# CANADIAN CLIMATE CENTRE

## REPORT NO. 91-7

# Sources of Proxy Meteorological Data for the Canadian Prairies

by

Lawrence C. Nkemdirim

ATMOSPHERIC ENVIRONMENT SERVICE

National Hydrology Research Centre
Saskatoon, Saskatchewan

1991

THIS REPORT HAS RECEIVED ONLY LIMITED CIRCULATION BECAUSE OF THE SPECIAL NATURE OF THE PROJECT. HOWEVER, REFERENCE IS PERMITTED IF THE WORDS "UNPUBLISHED MANUSCRIPT" ARE MADE PART OF THE BIBLIOGRAPHIC ENTRY, IN ACCORDANCE WITH ACCEPTED PRACTICE.

**OTHER CANADIAN CLIMATE CENTRE (CCC)**
**SCIENTIFIC SERIES INCLUDE:**

| | | |
|---|---|---|
| 1. | CS series | - CCC Climatological Study |
| 2. | CLI series | - CCC Climatological Memoranda |
| 3. | CDS/DS series | - CCC Climatic Data Summary |
| | | - CCC Documentation Sheet |

For further information on climatological publications contact the

Climate Information Branch
Canadian Climate Centre
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario M3H 5T4

# Sources of Proxy Meteorological Data for the Canadian Prairies

by

Lawrence C. Nkemdirim

A publication of the Canadian Climate Program

Printed on
recycled paper

Imprimé sur
du papier recyclé

## ABSTRACT

About 300 years of weather records exist for the prairies in a variety of documented sources. Daily temperature, precipitation frequency and wind direction have the most data. Records are most numerous and longest in Manitoba. Tree ring data exist but few were obtained in the prairies proper and still fewer predate historical records. The Middle and Late Holocene period dominate paleobotanical sources. Alberta and the North West Territories have the most data from both paleobotanical and archaeological sources.



## RÉSUMÉ

Il existe diverses sources documentées d'enregistrements météorologiques pour les 300 dernières années environ dans les Prairies. C'est pour la température quotidienne, la fréquence des précipitations et la direction du vent qu'il existe le plus de données. Les enregistrements sont les plus nombreux et de la plus longue durée pour le Manitoba. Il existe des données sur les cercles de croissance des arbres, mais peu d'entre elles ont été obtenues dans les Prairies proprement dites et encore moins d'entre elles sont antérieures aux enregistrements météorologiques. Les données sur l'Holocène moyen et tardif sont prépondérantes dans les sources paléobotaniques. C'est pour l'Alberta et les territoires du Nord-Ouest qu'existent les données paléobotaniques et archéologiques les plus nombreuses.

## ACKNOWLEDGEMENT

The author wishes to acknowledge the support and encouragement of Don Bauer (Atmospheric Environment Service) of the National Hydrology Research Centre Saskatoon. His deep interest in proxy meteorological data was a constant reminder of the value of this undertaking. I acknowledge the dedication of Ms. Debbie Little of the Geography Department, the University of Calgary, who produced the document. Thanks also go to the staff of the National Archives, Ottawa, the provincial archives in all three prairie provinces, and the Hudson Bay archives in Winnipeg.

## TABLE OF CONTENTS


| | | Page |
|---|---|---|
| 1. | OBJECTIVES | 1 |
| 2. | 10,000 YEARS OF CLIMATE HISTORY | 1 |
| 3. | PERIOD COVERED | 7 |
| 4. | AREA COVERED | 8 |
| 5. | SOURCES OF PROXY DATA | 10 |
| | 5.1 HISTORICAL DOCUMENTS | 10 |
| | 5.1.1 The Explorers | 11 |
| | 5.1.2 Trading Companies | 18 |
| | 5.1.3 Settlements and Homesteaders | 21 |
| | 5.1.4 Government Documents | 24 |
| | 5.1.5 Newspapers | 26 |
| | 5.1.6 Textbooks and Journal Articles | 28 |
| | 5.1.7 Churches | 29 |
| | 5.2 ASSESSING THE QUALITY OF DOCUMENTED SOURCES | 31 |
| 6. | PROXY METEOROLOGICAL DATA FROM PALEOECOLOGY | 34 |
| | 6.1 DENDROCHRONOLOGY | 34 |
| | 6.2 PALYNOLOGICALLY-BASED RECONSTRUCTION | 42 |
| | 6.3 LAKE SEDIMENTS AND OTHER PALEOHYDROLOGICAL EVIDENCE | 48 |
| | 6.4 ARCHAEOLOGICAL SOURCES | 52 |
| | 6.5 OTHER PALEOCLIMATIC INDICATORS | 55 |
| 7. | SPATIAL, TEMPORAL AND DATA ADEQUACY | 56 |
| | 7.1 SPATIAL COMPLETENESS | 56 |
| | 7.1.1 Historical Records | 57 |
| | 7.1.2 Prehistoric Records | 59 |
| | 7.2 TEMPORAL COMPLETENESS | 61 |
| | 7.2.1 Historical Records | 61 |
| | 7.2.2 Prehistorical Records | 63 |
| | 7.3. DATA ADEQUACY | 63 |
| | 7.3.1 Historical Records | 63 |
| | 7.3.2 Prehistorical Data | 64 |
| 8. | CONCLUSIONS | 67 |
| REFERENCES | | 71 |

## LIST OF TABLES


| | | Page |
|---|---|---|
| 1. | Terminology used in this paper to describe climatic variations of different origin and duration. Adapted from Landsberg (1976) | 3 |
| 2. | Characteristics of paleoclimatic data sources | 9 |
| 3. | Main features of explorers daily weather reports | 11 |
| 4. | Drought series for the Great Plains based on tree-ring analysis in Nebraska | 36 |
| 5. | Frequency data on survey records preserved in provincial archives 1869-1899 | 57 |
| 6. | Approximate beginnings of continuous proxy data given by region and expressed as a percentage of total data | 58 |
| 7. | Proportion of paleoenvironmental sources for proxy meteorological data | 59 |
| 8. | Meteorological journals contained in post journals in the Hudson's Bay Company Archives (except where otherwise indicated, each meteorological journal is contained in the post journal of the same name) | 62 |
| 9. | Meteorological journals from the Hudson's Bay Company posts, preserved in the library of The Royal Society, London | 62 |
| 10. | Proportion of periods covered by paleobotanical data based on 171 reference works on the Prairies and the Northwest Territories | 63 |
| 11. | Types of data contained in historical documents | 65 |

## APPENDICES


1. Location index map and numerical key identifying trading posts across Canada ..... 86
2. Examples of archival meteorological documents..... 89
3. Sources of proxy meteorological data for the prairies..... 93

## 1. OBJECTIVES

This report focuses on the review of available sources of proxy meteorological data for the Canadian Prairies, especially those which predate the beginning of regularly archived weather records. It is hoped that they will significantly extend the present data base and so assist in the reconstruction and profiling of historical and prehistoric climate events in the prairies including droughts and periods of exceptional wetness. Specific means to this end are (a) location and identification of sources which could provide monthly estimates of precipitation and temperature or other information such as soil moisture for the period immediately prior to regular meteorological observations, (b) preparation of a literature review including a bibliography of seasonal and/or annual estimates of precipitation and temperature for a period of a few hundred years prior to regular observation, and (c) examination of the spatial and temporal completeness of existing sources for paleoclimatological data for the prairies.

## 2. TEN THOUSAND YEARS OF CLIMATE HISTORY

Climate, the composite generalisation of weather occurring at a given place is a dynamic system involving not only averages of daily weather over an extended time period, usually no less than 30 years, but also the variabilities and extreme events characteristic of the weather over that time span. Climate does change and has done so fairly frequently when considered in the context of Earth's history. There are fluctuations varying from the "small scale" changes which may last up to a century or so, to the large scale events including the Great Ice Age and those climatic optima which lasted millions of years. No matter what scale is chosen, a variety of alterations can be found embedded within climatic periods, some of these assume an apparent significance sufficient to fool the unwary into classifying them as a major change. Landsberg (1976) attempted a standardisation of the

nomenclature used for identifying climatic variations of differing time and scale dimensions (table 1). It is clear that despite the best attempts a certain blurring of temporal and spatial scales is inevitable and this inevitability increases with the length of period investigated.

Earth is in the fourth interglacial period of the Pleistocene ice age which began about 300000 years Before Present (BP). This interglacial which began between 10000 and 14000 BP is marked by improved warmth and a poleward retreat of the Continental Ice Sheet. Heusser (1966) noted that the period has been punctuated with some striking fluctuations in temperature and precipitation. The Period 12000 to 10000 BP was characterised by a cool and relatively wet climate. This was followed by a global mild, even warm period. Lamb (1966) uses the dramatic and catastrophic readvance of the ice masses about 10800 BP and the destruction of entire forests caused by the ice invasion to illustrate the degree of variability which the climate is capable of even during a period of general improvement.

The continental ice disappeared completely in Northern Canada about 6000 BP. The climax of the post glacial warming was reached between about 7000 and 5000 BP worldwide, when annual temperatures were 2 to 3°C warmer than today. This post glacial optimum or hypsithermal was associated with relative dryness in North America. A cool episode occurred between 6000 and 5000 BP, signaled by new formation and/or advance of alpine glaciers. The warm period which followed lasted till about 3400 BP at which time cooling occurred once again. The warming that began around 2500 BP lasted until 1500 BP in Western North America. The latest ice advance which began c1500 BP reached its maximum southward penetration c. 1000 BP.

Table 1. Terminology used in this paper to describe climatic variations of different origin and duration. Adapted from Landsberg (1976).

| *Term* | *Duration* | *Known or Potential Origin* |
|---|---|---|
| Climatic Revolution | $>10^6$ years | geotechnical activity (continental drift, orogeny, large-scale changes in land and water distribution). Possibly solar variations. |
| Climatic Change | $10^4$ - $10^6$ years | changes in solar emission - aperiodic or periodic (period $\geq 10^4$ years)<br>changes in extraterrestrial insolation due to long-period changes in orbital elements (orbital eccentricity, ecliptical inclination, precession) |
| Climatic Fluctuation | $10^1$ - $10^4$ years | all other *natural* climatic variations with durations in excess of 10 years<br>aperiodic: volcanic activity<br>quasi-periodic: changes in solar emission (sun-spot rhythms), magnetic declination cycle<br>slow deep ocean currents<br>terrestrial feedback mechanisms |
| Climatic Iteration | <10 years | very short-term quasi-periodic *natural* variations,<br>quasi-biennial oscillation (2-3 years),<br>terrestrial - possibly atmospheric/ oceanic interaction |
| Climatic Alteration | 10 - ? years | anthropogenic causes - effects can be global, regional/subcontinental or local in scale<br>global scale: increases in atmospheric $CO_2$, $NO_x$, halocarbons and particulates<br>regional scale: power production, industrialization, urbanization, clearing of vegetation<br>local scale: urbanization, agriculture (clearing, tilling, drainage, irrigation), grazing, water storage, deforestation, afforestation |

Climates during periods earlier than 1000 BP can only be reconstructed from paleoecological data. Since then, however, records of climate have become increasingly more detailed due to the availability of historical accounts at least in the northern Atlantic sector (Stockton, 1977). The mild conditions of the post glacial optimum were nearly reached once more about 800 BP, culminating about 1200 AD when ice conditions around Greenland were much less severe than today. Northern hemisphere data suggests that the period after 1300 AD was one of widespread changes to cooler conditions – the Little Ice Age. Glaciers advanced in many parts of the world but the episode was brief. Worldwide glacial recession accompanied global temperature rises after 1850.

Brooks (1954) provided a more detailed climatic pattern of the last 1000 years for the Northern Hemisphere in general and the lands bordering the North Atlantic in particular. There were several climatic phases beginning with a mild relatively dry period from AD 1000 to 1250 followed by a rainier, stormy period between 1250 and 1400. A colder but less stormy period ensued from 1400 to 1600 AD when sea ice increased but the mountain glaciers were still relatively small. The "Little Ice Age" occurred from 1600 to 1850 at which time glaciers oscillated about an advanced position with three main maxima separated by a century or so – 1650, 1750 and 1850. Recovery from this ice age has proceed since 1850 with few major interruptions. Indeed some scientists, Idso (1988) for example, believe that the present concern over anthropogenically induced global warming is misplaced. They see the current climate as part of a general continuing recovery from the icy conditions of the first half of the 19th century.

Although the wind vane was invented around 100 BC and the rain gauge shortly after, it was not until the 16th and 17th centuries that key meteorological instruments such as the hygrometer, the thermometer and the barometer were developed. Only then did the era of scientific observations of the weather begin.

However, instrumental meteorological observations based on standardised procedures and practice did not get under way until the nineteenth century. It was not until the end of that century, and with the encouragement of the International Meteorological Organisation (IMO), the predecessor of the World Meteorological Organisation (WMO), that instrumental records of reasonably good quality were available especially in Europe and North America. Thereafter began an era of climatic analysis and interpretation based on directly sensed numerical data. Prior to the mid nineteenth century, instrumental records of temperature and precipitation were kept with some dating back to the end of the seventeenth century. But the records were of uneven quality due to the crudeness of pioneer instruments and the lack of established instrumental exposure and observation procedures. Changes in observation sites, breaks due to wars and lack of station history are other factors which sometimes compromised the use of early recorded data for climatic reconstruction. The interior of North America was especially poorly served before the mid nineteenth century when Europeans with meteorological interests began to settle. Indeed, Officers of the Hudson Bay Company at Moose Factory were explicitly discouraged from maintaining chronicles about the weather and climate. In a letter dated 18 May 1800 written by the Governors and Committee of the Company in England to John Thomas, the Officer in charge of the Moose Factory, the trading post was instructed as follows:

> *Particular transactions may be always communicated in the journals, but diaries of wind and weather are to us useless and need not be kept . . ..*
>
> *(Hudson Bay Archives A.6/16 folio 97d).*

Even without instrumental data, the earth, its crust, landform, and waters, and the life it has supported can provide a chronicle of the previous climate. Vegetation, soils, rocks, ice cores, lacustrine and riverine sediments and the fossils of fauna

and flora preserve encoded climatic records. Human and wild life migration patterns, and the quality of their habitat and diet were all in part functions of the prevailing climate. In the hands of a skilled paleoclimatologist such geological, paleoecological and paleobiological evidence are invaluable tools for climatic reconstruction and mapping.

Meteorological and climatological data inferred from the paleoenvironmental evidence are referred to as proxy. We seek proxy data to enrich the length of our climatic history, to provide clues about past changes and variability in climate and ecosystem and to improve our understanding of projected future climatic scenarios. The procedure followed is rooted in the principle that the present is the key to the past, i.e. that the relationships which currently exist between climate and a life form, vegetation for example, are identical to those established between them in the past. Unfortunately, the past is not always an exact analogue of either the present or the future. Adaptation and mutations of life forms with time may account for errors of interpretation. An ecosystem of the past could have existed outside of the climatic bounds that we find apply in the current time.

Proxy data also include numerical data obtained from weather reports contained in diaries, personal memoirs, and letters, in mentions of hydrological phenomena including river stage, ice formation and break up, groundwater well levels, and in comments on phenological events. Such data may not have been kept in numerical form originally but their content is such that reasonable quantitative estimates of weather data can be determined.

Climatic reconstruction based on proxy data must be carried out with extreme caution because the climatic signals gathered from these proxies are highly dependent on what Environment Canada (1986) refers to as their own distinctive performance characteristics, calibration techniques and limitations. It is not uncommon to obtain two opposing interpretations from a fossil vegetation using

two different calibration techniques. Even the best efforts supported as they often are, by advanced radiocarbon dating methods, highly sophisticated multivariate statistical procedures and powerful computers still yield data with large margins of error, large enough in some cases to mask the significant qualities, including time and space dimensions, of the information sought. Evidence is best when signals derived from several independent analytical methods converge.

## 3. PERIOD COVERED

The period covered by this report is wholly within the Holocene which began approximately 11000 to 10000 BP. The report extends from the retreat of the Laurentide Ice Sheet into Northern Saskatchewan to the first decade of the twentieth century, the later date being about fifty years after the establishment of regular meteorological networks in the prairies.

For convenience, two periods are considered. Period 1 is the pre-European settlement period from c. 10000 BP to c. 1700 AD. Proxy data sources for Period 1 are predominantly paleoenvironmental and paleoecological. Period 2 is the post-European settlement period (c. 1700 to 1910). Documented chronicles of the weather by trading companies, pioneer settlers, explorers and government agencies dominate the sources for proxy data for this period. Proxy data sources for the two periods are not mutually exclusive. Stockton and Fritts (1973), for example, reconstructed the climate of mid 1800 for parts of the prairies from paleoecological evidence derived from Lake Athabasca. Comparison of their results against documented data from period 2 demonstrate how useful such overlaps can be in climatic reconstruction.

As long as we deal with well documented and collaborated historic information, we have no difficulty in fixing the time in which a climatic event occurred. However, and in light of the significant margin of error involved in

every dating method now in use, and that the reality that this margin increases the farther one goes back in time, we cannot expect to fix the time of major prehistoric climatic events with the type of precision associated with instrumental data.

Kutzbach (1975) summarised the sampling time – space/time dating accuracy dimensions of paleoclimatic data sources (table 2). The table shows varying degrees of accuracy for the dates associated the reconstructed climate. This accuracy depends on both the variable used, pollen concentration or written records for example, and the minimum number of years contained in each sampling interval. Thus temporal determination of specific events will not have near the same accuracy in period 1 as they would in period 2. Furthermore, while it is possible to determine yearly, seasonal, monthly and in some cases daily weather events from written records or oral history with some exactitude, annual and seasonal specification of climatic events determined for period 1 though possible will be inexact.

## 4. AREA COVERED

The area of interest is the Canadian Prairies. This is defined as the predominantly grassland region bounded in the east by the territory immediately east of the Assinaboine – Red River Valley and in the West by the foothills of the Rocky Mountains. The Northern boundary is the southern limits of the Boreal forest. The Canadian prairies are part of the grassland area of the North American Great Plains which stretches from Texas and New Mexico in the United States through Manitoba, Saskatchewan and Alberta in Canada. Because of this connection with states South of the border, reference to the American experience is a valuable source of information on the climatic profile of the Canadian prairies for both periods 1 and 2.

Table 2. Characteristics of paleoclimatic data sources (after Kutzbach, 1975).

| *Data Source* | *Variable Measured* | *Continuity of Evidence* | *Potential Geographical Coverage* | *Period Open to Study (yr)* | *Minimum Sampling Interval (yr)* | *Usual Dating Accuracy (yr)* | *Climate Inference* |
|---|---|---|---|---|---|---|---|
| Bog or lake sediments | Pollen-type concentrations, mineralogic composition (normal core) | Continuous | 50° to 70°N | 10000 | 200 | ±5% | Temperature, precipitation and soil moisture |
| Layered lake sediments | Pollen-type concentrations (annually layered core) | Continuous | Mid-latitude continental | 10000+ | 1-10 | ±100% | Temperature, precipitation, and soil moisture |
| Tree rings | Ring width anomaly, density, isotopic composition | Continuous | Mid-latitude and high-latitude continents | 1000 (common) | 1 | 1 | Temperature, runoff, precipitation, and soil moisture |
| Written records | Phenology, weather logs, sailing logs, etc. | Episodic | global | 1000+ | 1 | 1 | varied |
| Archaeological records | Varied | Episodic | global | 10000+ | — | varied | varied |

Additionally, we are reminded by Sorenson et al (1971) and Reider et al (1988) that the grassland boundaries have shifted in response to climatic change and variability during the Late Wisconsin and the Holocene. As a result, the literature review will include reference to evidence of climatic conditions which may lie outside the boundaries of the present target area.

## 5. SOURCES OF PROXY DATA

The sources of proxy data examined include the following: Historical documents, tree rings, pollen, paleosoils, plants and animal fossils, lakes and river sediments, archaeological and anthropological evidence. Each of these has certain strengths as well as weaknesses. Their scope, potential and limitations are described very well by Hoeller (1982). A list of sources by type and location including key reference journals, leading institutions and scientists involved in paleoclimatic studies as they pertain to the prairies is provided in Appendix 3.

### 5.1 HISTORICAL DOCUMENTS

Unlike Europe where there is a long history of written accounts of the weather dating as far back as the 14th century (Lawrence, 1972), reliable documents for proxy climatic data did not exist in archivable form in the prairies prior to the arrival of the first europeans. Historical documents useful for reconstructing climate in the prairies include

1. Diaries, memoirs and journals of expeditions and explorers.
2. Post diaries of trading companies and other fur traders.
3. Diaries, memoirs and reports kept by group settlements and independent homesteaders.
4. Government documents.
5. Journals kept by churches and missionaries.

5.1.1 *The Explorers*. Explorers and leaders of expeditions in Western Canada left behind journal, survey data, diaries and personal memoirs which together constitute rich sources of early climatic record for the prairies. Almost all the explorers of the West kept a daily chronicle of the weather either because they were specifically mandated to do so as was the case in the Palliser expedition (Spry 1968) or because their progress depended on it (Gladman 1858).

Table 3 shows the major features of the daily weather reports contained in expedition diaries

Table 3. Main features of explorers daily weather reports

| ***Weather Element*** | ***Style of Presentation*** |
|---|---|
| Temperature | Numerical data frequently given, qualitative description (warm, cold . . .) common |
| Wind | Direction reported in Octas, speed usually qualitative (light . . . gale) |
| Precipitation | Frequency given; distinction between snow and rain; depth usually non numerical except following extreme events |
| Weather | Sky conditions reported; general impression (fine, warm . . . disagreeable) given |

Because of the "transect" nature of the entries, explorers diaries are not by themselves sources for continuous data for a fixed portion except where arrangements were made to maintain an observation station after the departure of the expedition. Daily entries represent one snapshot of the climate as found during a short visit and may not represent average conditions for that place even for that time of the year. As Coupland (1958) observed, unfavourable reports of the agricultural potentialities of the prairies were made as a result of explorations in dry periods such that the area was designated as the Great American desert

(Webb 1931, Pike 1810). In 1822, Stephen Long described the American Great Plains as "wholly" unfit for cultivation, and of course, uninhabitable by a people depending on agriculture for subsistence (Borchert 1971). Tree rings and other data later confirmed that 1822 was indeed drought plagued (Weakly 1965). Conversely, traverses made in periods of sufficient moisture prompted accounts of the great fertility of the land and its suitability for settlement (Aughey 1880, MaCoun 1882). However, where regional homogeneity is known to prevail such diaries could be extremely useful for extrapolating average regional weather for spatially persistent events such as droughts.

In the hundred years between 1760 and 1860, many explorers and expeditions travelled through the American northwest including the Canadian and American prairies. The intention here is not to review all their activities, rather it is to highlight the contribution of a few key ones to our knowledge of the weather and climate of the west over those hundred years. The Champlain Society in Toronto has published several official diaries of explorers of the west including weather records and anecdotes. The National Archives, Ottawa has a comprehensive list of the explorers as well as many original documents compiled during the expeditions.

*David Thompson* spent the period 1784-1797 in the Service of the Hudson Bay Company (HBC) before joining the Northwest Company (NWC). He was employed mainly as a geographer and explorer and gained fame for his exploration of the Columbia River. He kept a part time home in Rocky Mountain House, Alberta since shortly after it was established as a settled community in 1799. From this base, he travelled extensively throughout the West. A good example of his meticulous documentation of the weather is his daily account of the weather in the Stony River district from September 23, 1797 to July 15, 1798. Each entry in the journal began with a general description of the day's weather, ice

conditions in streams, etc, for the date. Occasionally he would comment on the presence of birds and other forms of wildlife usually in the context of departures from established normals, as indicated by co-operating natives. Tyrell (1916) published the official diaries of the Thompson expedition. Glover (1962) edited another version.

*Alexander Mackenzie* made several trips to Western Canada between 1739 and 1793 mostly sponsored by the NWC. Although his journey in 1789 by Bark Canoe in search of a passage by water through the northwest of America from Athabasca is the best known (Sheppe, 1962), he had made at least two previous significant explorations of the West. In 1739, he penetrated the Saskatchewan River covering an extensive area of what is now northeast Saskatchewan. Between 1785 and 1787 he explored the Churchill district of the Hudson Bay. Mackenzie kept a daily diary of temperature, wind, and weather. Unfortunately he broke his thermometer in 1792 during his journey to the Pacific. Although the accident interrupted his temperature data he continued to record other aspects of the weather.

Perhaps the most impressive chronicle of the prairie weather in the early 19th century are those found in the diaries of *Alexander Henry, the Younger*, again an employee of the NWC. He was in the prairies between 1800 and 1811. He travelled through Manitoba, Saskatchewan and through Alberta to the Rockies. He was meticulous about temperature measurements including an insistence that they be measured in the shade. Snow depth and sky conditions were given all in a carefully laid out tabular form similar to those shown in Appendix 2. The best example of this excellent record keeping is the "meteorological observations made 1 September to July 4, 1808" for Pambian River (Champlain Soc. 1988). In addition to 3 hourly summaries of the weather, he provided information on the type of thermometer used, its calibration, range and exposure.

*Captain John Palliser,* a Fellow of the Royal Geographical Society, who earlier had travelled extensively through North America, led a British Colonial Office expedition through the southern prairies of British North America with a mandate to compile as much information as possible on the geographic feature of the Plains, their geology, climate, flora and fauna, and resources. He was supported by a technical team which included Dr. James Hector, naturalist and physician and Wright Blakiston, magnetic observer. They began their expedition in 1857 and stayed in the southern Prairies through 1859. The following excerpt taken from Spry's contribution on Palliser in the *Dictionary of Canadian Biography* (Halfpenny, 1966) include the routing of the expedition, and the time and geographical area covered.

Palliser sailed for New York on 16 May 1857 with Hector, Bourgeau, and Sullivan. At Sault Ste Marie they picked up two waiting canoes with their voyageur crews and proceeded by steamship across the ice-covered Lake Superior to Isle Royale, Mich. There, on 12 June, they embarked in the canoes and after a month's arduous paddling and portaging reached Lower Fort Garry (Man) on the Red River. While organizing men, horses, carts, provisions, Indian presents, ammunition and other supplies, for which Simpson and the HBC had made preparation, the explorers consulted knowledgeable local people and studied the Red River Settlement.

On 21 July the expedition started on its journey across the plains, heading south up Red River to the American boundary, where they made careful observations in conjunction with a chance -met American land surveyor, Charles W. Iddings. From Pembina (N. Dak.) the party travelled west via St. Joesph's (Walhalla) and Turtle Mountain (Man.) to Fort Ellice where they were joined by James McKay, a noted mixed-blood guide. They made a quick trip to the boundary at Roche Percée (Sask.) before setting off for the South Saskatchewan River. Near the Elbow they turned northeast to Carlton House (Sask.) on the North Saskatchewan River, which was to be their base for the winter. Palliser went off via St. Paul (Minn.) to New York to make application to the Colonial Office for more time and more money. While waiting for a reply he revisited New Orleans, returning to Carlton House for an early start in the spring of 1858. Meanwhile, Blakiston had joined the party at Carlton House, having brought the delicate instruments needed for magnetical observations by way of Hudson Bay, and he carried on hourly observations. Hector had journeyed to Fort Edmonton to recruit men for the next season's work.

On Palliser's arrival, the explorers headed west between the two branches of the Saskatchewan River. Near modern Irricana (Alta.) the party separated to probe into the mountains for feasible passes. Palliser and Sullivan made a dash to the American boundary before crossing the mounts by the North Kananaskis Pass. Returning by the North Kootenay Pass, they rejoined the rest of the party to winter at Edmonton.

Blakiston, who had traversed both Kootenay passes, now left the expedition because of a quarrel with Sullivan which had widened to include Palliser. Hector had crossed the mountains through Vermilion Pass and returned by the Kicking Horse Pass; he devoted the winter

to further exploration. Palliser hunted and examined the country south and east of the fort and then, with two newly arrived friends, Captain Arthur Brisco and William Roland Mitchell, travelled to Rocky Mountain House (Alta.) to get to know the Blackfoot and Piegan Indians who frequented it, as he planned to travel through their country the next season. At Fort Edmonton the whole party enjoyed the hospitality of chief Factor William Joseph Christie and the highly sociable Palliser, with the aid of Mrs. Christie, gave a tremendous ball.

In its final season, 1859, the expedition travelled southeast to the forks of the Red Deer and South Saskatchewan rivers in an attempt to connect with their westernmost point in 1857, and then south to the Cypress Hills, where the party broke up. Brisco and Mitchell went to Fort Benton (Mont.) and down the Missouri. Hector travelled northwest to cross the Rockies by Howse Pass in a final but unsuccessful attempt to discover a way through to the Pacific coast. Palliser and Sullivan journeyed directly west, then north, to cross the mountains by the North Kootenay Pass and follow the Kootenay River down to the Paddler's Lakes (Bonners Ferry, Idaho). Sullivan took the horses overland to Fort Colville (Colville, Wash.), while Palliser voyaged down the Kootenay River and Lake in an Indian canoe.

While in the prairies between 1857 and 1859 Palliser not only kept a daily diary containing weather data in the country through which he travelled, in his report to the Colonial Office, he also described in addition the climate of the region west of the Red River in the context of its suitability to support commercial agriculture (Palliser 1860). On an area in southern Alberta, an area now known as the Palliser triangle he wrote:

> *The general bareness and absence of valuable timber made it unsuitable for settlement . . .. There is throughout the whole region a great scarcity of rain, but in a few places here and there where the land rises above 300-400 ft. good grass and some timber . . . appear.*

He highlighted the weather of 1859 by noting that the Bow - South Saskatchewan River corridor had experienced an unusually dry summer:

> *The few swamps on which we were wholly dependent for water, with a few exceptions were brackish and impregnated with sulphur and grass, barely sufficed to feed the horses. The very insignificant tributaries to the South Saskatchewan were nearly dried up, appearing here and there in pools of water.*

That description complements his negative view of the climate of the region expressed in an earlier observation:

> *There have been and possibly still exist, more particularly in Canada, most erroneous opinion concerning the country and climate of the Red Deer and the West. I have seen it described as superior even to the SW peninsula of Canada, which to any observant person must appear absurd.*

The Palliser papers show that meteorological observations were being taken uninterruptedly at several locations in the western prairies between 1858 and 1859.

> *I have before said that the meteorological observations were included in hourly series, but that terminating on 16th April (1858) there were afterwards kept up 3 times a day until the expedition left its winter quarters in mid June. I, however, left a thermometer which was registered by the gentleman in charge and those under him during summer and autumn while I was absent, and on my leaving Carlton for good in December 1858, I still left it there, and have now received another six months observation. The climate therefore of this station is well determined.*
>
> *(T. Blakiston, 1858)*

In this final report (Palliser, 1859) included charts on climatic averages for various parts of the prairies. His account of the sources for his data indicates the expanding network of archived meteorological data in the west.

> *The material from which knowledge of the climate of the country (prairies) was (obtained) was drawn from regular meteorological observations carried on simultaneously at Red River Settlement and Fort Carlton on the Saskatchewan River. At Red River two distinct sets of observations were kept up, one at the*

*hospital of the Royal Canadian Rifles under the direction of Dr. Stranaghan, while the other was the continuation of a register kept by Donald Gunn of St. Andrews. That at Fort Carlton was the observation made during the stay of Capt. Palliser's expedition and afterwards by Richard Hardisty, the gentleman in charge and those under him. These commenced November 1857. But besides these simultaneous observations others have been made on former occasions which, I may mention those of Lt. Lefroy at Lake Athabasca and Fort Simpson 1843 - 44. Those of Sir Richardson and Dr. Rae at Great Bear Lake in 1848-49, those of Franklin's two journeys, besides a number of registers and detached observations collected in Sir John Richardson's "Journal of a Boat Voyage". Also with a view of assisting me in drawing a comparison with the climate of Canada Professor Kingston in charge of the Provincial observatory at Toronto has kindly furnished me with numerous records of meteorological observations.*

*(The Palliser Papers, 1859)*

The Palliser account of the climate of southern Alberta and eastern Saskatchewan is widely used in studies of climate and land use in the southern prairies (Jones, 1987) and in paleoclimatic interpretations (Wilson and Hills, 1984, Banfield 1958).

Other explorers whose diaries contain useful weather data include John Stuart at Rocky Mountain House (1805-1806), John MacDonald of Garth in Ft. des Prairies 1806-1808, Upper Red River 1808-1811 and the Columbia 1811-1812, Dawson (1858) on the country between Lake Superior and the Red River Settlement, John Fremont (1848) in the US Great Plains, Joseph Smith (1764), William Pink (1766-1770), and Mathew Cocking (1772-73, 1774-75 and 1774-1776) in Saskatchewan. Daniel William Harmon in the North American interior (lat. 47°-58°), 1800-1819, Zebulon Montgomery Pike who travelled through the Great Plains of the US around 1810 (see Jackson, 1966) provided some graphical description of the

climate of the American Great Plains during the first two decades of the 19th century. In 1810, Pike who had become convinced of the unworthiness of that area for agriculture wrote "in time the mid continent region . . . may become as celebrated as the deserts in Africa". Henry Ware travelled down the St. Lawrence River through the Great Lakes into the Western Prairies of the US between 1839 and 1843. He invariably began his daily entries with remarks about the weather. Occasionally he would summarise the season as the following entry on the variability of the weather of 1840 in the western prairies illustrates

> *The weather was much cooler than our last visit . . . during this four months we have experienced viscitude of climate, from extreme heat to cold – but on the whole notwithstanding frequent thunderstorms and heavy deluge of rain on the prairies (luckily of short duration) the weather has not treated badly.*
>
> *(Henry Ware: Hunting Tour of the Western Prairies, 1841)*

Baird (1881) described his travel through the northwest and wrote extensively about his journey between the Red River and Saskatchewan and the weather he encountered.

5.1.2 *Trading Companies and Fur Traders.* The opening of Western Canada to european traffic and documented meteorological accounts which followed it are strongly linked to the fur trade, the trading companies which controlled it and the trading posts the companies operated. Appendix 1 shows the distribution of trading posts, the year in which they were founded (A1.1) and their owners (A1.2). Only posts of duration four years or more are shown. They constitute 41% of the total number established between 1600 and 1870..

The two companies dominated the fur trade in the west during the 18th century. The Hudson Bay Company (HBC) was incorporated in 1670 under a

charter which provided a monopoly to trade extending over the territory drained by the rivers flowing into Hudson Bay. Throughout the 18th century, the company persued a policy of gradual expansion into the interior and the prairies while confining its primary activities to the shores of the Bay. The Northwest Company was formed by a group of independent traders, many of them French, in 1775. In 1804, it absorbed the New Northwest Company (the XY Company) and became the major competitor against the HBC when the latter moved inland from the Hudson Bay. Wallace (1934) provides a comprehensive list of the officers of the company and their journals. The HBC and NWC merged into an expanded HBC in 1821.

Between them, the NWC and the HBC both before and after their merger encouraged the growth of weather records through (a) sponsorship of expeditions into the interior, and (b) establishment of trading posts each of which maintained a post journal. The post journals included financial reports, day to day business and reports on daily weather.

Appendix 3 shows a map of the various trading posts established by the major traders. Clearly the most useful in terms of continuity are the 24% which were in operation for more than 15 years. But even the shorter term ones can be valuable if their duration coincided with periods of major climatic events especially those of an episodic nature.

The history of documented continuous weather records for specific prairie locations parallels the spread of trade and settlements in the west. A summary of the westward push of european presence is provided in *The National Atlas of Canada* (1987):

> *1670 to 1713.* The French Traders had begun to leave their original settlement (on the Atlantic coast and the St. Lawrence River) and a sufficient number of trading posts was established to enable the traders to make direct contact with

the tribes of the interior . . . The Hudson's Bay Company (HBC) had now begun to build posts on Hudson Bay and James Bay.

*1713 to 1763.* During this period the HBC more than doubled the number of its posts on Hudson Bay and James Bay. The French, excluded from this area by the Treaty of Utrecht of 1713, built posts from Rainy River to the mouth of the Saskatchewan River and on the North Shore of the Gulf of St. Lawrence.

*1763 to 1787.* Trade during this period was dominated by a large number of independent traders and small trading companies who adopted the French system of wintering with the Indians in the interior. To compete, the HBC was forced to establish posts in the interior also, starting with Cumberland House in 1774. As a result, the trading areas were extended along the Saskatchewan River and partly into the Athabasca River drainage basin.

*1787 to 1821.* This is the period of strong competition between the NWC and HBC. It is probable that during this time, more trading posts were built per year than at any other time. In 1795, the NWC controlled the majority of the trade, the HBC and the independents together controlling only one third as much. However, in the following 25 years competition became so strong from the HBC, and the NWC's financial position became so poor, that the two rivals united in 1821.

*1821 to 1870.* With an end of competition, the reorganised HBC flourished during the 1st half of this period. With exploration coming to an end and permanent settlement just beginning to spread westwards, new trading posts were built mainly in British Columbia. By the end of this period agriculture and forestry had overtaken the fur trade as the resource base of the Canadian economy.

The earliest records were those on ice and wind conditions on the Hudson Bay and Straits, and the rivers and lakes leading inland from them. Some of the early records were those kept by Capt. James Knights in 1717. By 1750, ice conditions were figuring prominently in post journals. One of the most detailed of these is the Severn House Journal kept by Humphrey Marten (1759-60). Dates of freezing of the Albany River were reported continuously from 1846 to 1905.

Cumberland House trading post established by the HBC in 1774 appears to be the first one to maintain a continuous weather data base for a fixed position. Weather records began at that post in the same year. Earlier records exist in the files of the NWC but lack similar continuity.

The period 1787 to 1821 saw the expansion of meteorological documentation through a wider geographical area within western Canada especially following the 1814 directive issued by HBC headquarters in the United Kingdom making routine weather observations almost mandatory for posts around the Hudson Bay.

Instruments were also distributed to the posts along with instructions on observation procedures. Later, explicit encouragement to maintain weather diaries came from the US government which requested records from Cumberland (HBC, 1875). In 1863, The Smithsonian Institute listed HBC posts Fort Rae, Rigolet, Fort McPherson, Fort Anderson, Fort George, Michipotar and Kenogamissi among the meteorological stations which supplied data to the Institute.

Anderson (1961) summarised the formal duties of a weather observer and from all accounts, it would appear that many of the stations had adopted similar practices.

> *One of my regular duties (c. 1910) was twice daily taking observations for the Dominion Meteorological Office in Toronto with thermometer (dry and wet bulb), barometer, anemometer, rain gauge (snow gauge in the winter), records of clouds, thunderstorms, etc., etc. It was here (Moose Factory) in January 1911 that I recorded – 52°F the lowest temperature I have experienced. The daily meteorological observation were summarised on weekly abstracts and mailed out and when opportunity offered.*

The HBC later became official observers at some locations for what eventually became the Canadian weather service. In 1882, it took over the weather observation for Edmonton.

5.1.3 *Settlements and Homesteaders.* The Red River Settlement established between 1811 and 1812 owed, for its early fortunes or lack there of as much to its location as to its climate. Sutherland (1938) noted that the arrival of the settlers in 1811 coincided with harsh winter conditions. Alexander Henry

described how dependent the settlement was on the vagaries of the weather. Commenting on the impact of the Red River flood of 1826 and 1852 he wrote:

> *The settlement (Selkirk) gradually prospered although in 1826 and again in 1852, the farmers were driven from their holdings by floods. The houses were not carried away but all signs of cultivation were destroyed and the land could not be sown in either year.*
>
> *(Sutherland 1938)*

Bell (1898) noted that 1890 was the culmination of a 9-year drought and grasshopper infestation at Selkirk (see also Mackay, 1978). Lord Selkirk's memoirs (HBC, 1941) while not by any account a weather diary is punctuated with enough significant information on the climate to regard it as a proxy source for weather data. It is significant that a meteorological register was established in Fort Gary sometime between 1840 and 1850, some thirty to twenty years before weather observations began on a regular basis at St. John's College, Winnipeg.

The growth in the number of homesteaders in the central and western prairies around 1850 and thereafter, increased the size of territory in which records were kept. Personal journals, memoirs and letters exchanged between friends, relatives and functionaries were punctuated with news about the weather, usually an early item in the letters since they served as gentle openers. Such documents frequently compared the current weather with other types with which the correspondent and or the eventual recipient was familiar in either time or place and often in both. An excerpt taken from the memoirs of Readman (1964) demonstrates the homesteader's skill at weather observation as well as the ability for climatic recall. Writing about the winter of 1906-1907 in North Battleford, Saskatchewan he wrote:

> *The first two weeks of January 1907, it was terrible. For 6 solid days the thermometer stood at 65 below*

> *zero. It never moved, that was a terrible week . . .. That winter 1906 and 1907 was the worst winter I or any one saw from 1900 to the present day (1964) and that was a longtime and I have seen some very bad winters since. It was a very late spring (1907) and it made seeding very late. It was well into June before it was all finished. Now the cattle could not run where they liked, so fences had to be built, cattle had to be kept off the crops . . .. But owing to the late spring, the crop is very late too and quite likely to catch all the frost . . .. On the 10th of September it was my wife's birthday, well, I looked out the window that morning everything was buried, but in two days the snow had gone again but it soon turned cold. The ground was frozen before we had finished harvest, . . .. Threshing was a very cold job.*

The numerical form of the data provided in the excerpt suggests that homesteaders either kept thermometers and some form of snow/rain gauge or that they had access to them. Some like Horrel (1907-1946) kept diaries exclusively devoted to the weather.

A number of homesteaders travelled across the southern prairies and left behind their impression on the climate of the period. Writing about the drought of 1887, Trueman opined:

> *I can say now that we have seen enough to convince us of the following facts: First, that the northwest has a soil exceptionally rich in all elements necessary for the production of food for the sustenance of man and beast . . .. The cause of disappointment has been the dry seasons, the frost and the prairies fires . . .. All who have had any lengthened experience in the country maintain that the last two or three years of drought were exceptional, and they believe that they have now. entered upon a cycle of of years that will give sufficient rainfall. In 1882, the district on which we have travelled was so wet that it was with difficulty a team could cross it. Since that time, almost every coulee and slough has been dried up, but it is evident by the appearance of*

> *many of these places that their normal condition is one in which there should be water in considerable quantities. Last year, we are told, the ground was so dry in the fall that there was not in it moisture enough to freeze . . ..*
> *(H. Trueman, the Regina Letter, October 8, 1887)*

The provincial archives have a large collection of personal memoirs, several with very significant views on the weather.

5.1.4 *Government Documents.* The North West Mounted Police (NWMP) was established in 1873 to police the area from the Western boundary of Manitoba to the Rockies. Local records were kept at each outpost and several had references to the weather. The weather records were not always systematically compiled and were more likely to be qualitative than numerical. The Prince Albert NWMP local records are good examples of how dependent the entries were on the personal interest of the officer charged with responsibility for them. In 1884, entries were occasional and qualitative: "Heavy rain and thunderstorm at night, high wind, raining all day". In 1898, under a different officer the day's report opened with capsule comments on the weather, figures on temperature were given (Sunday, November 27, 1887 "weather very cold -20°F). The records of the Snake Plains Detachment was even better "alternate snow storms and sunshine. Fine a.m., showery p.m. . . . very cold, 35 below zero . . . 31 below last night" (National Archives of Canada).

The most consistent weather event reported in the records is wind direction. Precipitation amounts were rarely given except when the fall of snow was exceptionally heavy.

The occasional numerical entries encountered in the diaries suggest one of three possibilities: (a) that the officer had access to instruments, (b) that a register (an observation post) was close by, and, (c) that the data was an educated guess. In

light of the fact that the NWMP was formed relatively late in the century by which time several trade posts had established regular observations, it appears that the second is the most likely of three possibilities. The remaining two should not be discounted however. In fact, the first official meteorological observations in Calgary were taken by the NWMP shortly after their arrival in 1876.

Relevant government documents useful for climate and weather reconstruction include data collected by the Geological Survey of Canada, the Dominion Statistical Abstracts and the Annual Reports of the Department of Agriculture. The last of those sources would normally include averages of monthly temperature and precipitation for selected towns in the prairies as well as annual averages. In addition, several committees specifically struck to examine the economic potential of the West produced reports which devoted considerable sections to the areas climatic resources. Examples are the Schultz report on "Food Production in the Northwest" and the recommendations of the Committee on Agriculture in the Northwest on the "Agricultural Potential of the Area From Whitemud River to Ft. Pelly, Saskatchewan and Hays Lake" (Manitoba Provincial Archives). The minutes of meetings of various farm groups such as the Northwest Farmers Union and, the Farm Women's Association contain very significant climate information. Municipal and other local governments also kept records on the weather especially on those events like floods and droughts which threaten the economic health of their towns.

Canada's Weather Service began in winter 1839-40 with the establishment of an Observatory at Old Fort York (Toronto). However, it was not until 1871 that a truly national network was founded following the initiatives of Professor George Kingston of Toronto's King's College. For the prairies, the Winnipeg station opened in 1872 was the first to be "officially" recognised. But by then several unofficial ones including Calgary and Edmonton were already in existence.

5.1.5 *Newspapers.* The first newspaper in the Prairies was the *North Wester* which began publication at Selkirk on December 28, 1859 as a bi-weekly. From then on several newspapers appeared in the West. The *Battleford Saskatchewan Herald* was founded in 1878. In Alberta, the *Edmonton Bulletin* and the *Calgary Herald – Mining and Ranch Advocate* were established in 1880 and 1883 respectively. Several regional papers quickly followed. Most failed while others had a name change, some several times within a few years.

Newspapers provided summaries from data supplied by meteorological registers which had apparently become part of a growing national network. Temperature, usually daily minimum and maximum, and precipitation were reported regularly and monthly summaries provided (Appendix 2). But since these reports were based on data obtained from established stations, it is doubtful that the summaries can contribute any information beyond what the registers themselves provides. But the value of newspaper reports does not lie solely with the summaries. They occasionally published pieces of information which by themselves are excellent proxy meteorological data sources. The *Battleford Herald's* summary of major events of April 1897 included the following:

April 1 – Ducks seen
7 - Ice in Battle River commenced to move
8 - Grass beginning to sprout
9 - Battle River clear of ice
10 - Ice in Saskatchewan River commenced to move
11 - Snow all gone
12 - Rain and snow fell

In 1879, the *Winnipeg Daily Times*, recounting the problem which City Hall was having with flood control at the time, reflected:

> *. . . every one who was here will remember the Flood of 1877 which endangered City Hall, and extended as far north on Main Street as Logan Street. This was of course caused by the overflow of the gully and swamp and also the filling up of the gully crossing Main Street.*
> *(Winnipeg Daily Times, Wednesday, April 16, 1879)*

Other examples of hydro-meteorological indicators found in newspapers include: streamflow;

> *On April 12, the velocity of the current on the river Assiniboine per hr. is 21,680 miles, on the 13 it had decreased to 21,634 miles and to the 18 21,464 . . . the water level dropped 2 ft. 10 in. Since the 12 the river having been perfectly ice free since April 13.*
> *(Winnipeg Daily Times, April 20, 1879)*

and soil moisture;

> *The roads (waterlogged) are rapidly getting into good condition and a few more days of sunshine will probably harden them.*
> *(Winnipeg Daily Times, April 29, 1879)*

and droughts and duststorms;

> *A few years ago, at this time of the year we were cursed with disagreeable suffocating and provoking sand storms. Sometimes they would last for several days in succession. We firmly believe we shall have none of consequence this spring. The climate is surely improving.*
> *(The Salina Journal, March 1, 1877)*

> *Tuesday was by all odds the most disagreeable day of the season for dust. It (the dust) insinuated itself through cracks and keyholes in clouds. Abilene should have a street sprinkler . . . and thus escape the annoyance.*
> *(Abilene Chronicle, August 31 ,1877)*

In addition, papers carried news about severe weather outside the immediate local area, tornadoes and snow storms were favourite subjects. These are useful for assessing weather at the regional and, occasionally, the continental levels.

5.1.6 *Textbooks and Journal Articles.* Textbooks and articles in learned journals are additional sources for climatic data and interpretation for both the post-European era and the century or so preceding it. Grayson (1975) published a bibliography of literature on North American climates describing the past 13,000 years. Staton (1931) compiled a bibliography of sources of information on the Canadian Northwest. Parker (1948) reviewed the activities of the early explorers of the West. Lowe (1961) provided a historical account of Canada's pioneer weather observers.

Malin (1944) catalogued a cluster of severe droughts in the middle and later 1860s as well as a period of relatively favourable conditions through most of the years between 1872 and 1882 in the American midwest. Aughey (1880) published his conclusion on the relationship between farming and rainfall attributing the favourable period of the middle and late 1870s to "rainfall following the plough". Wright (1976) reconstructed the regional impact of drought and fire upon the vegetation cover in the American Great Plains during the period immediately preceding white settlement. Dawson (1879) compared the climate of the Peace River district with that of the Edmonton area and concluded that both areas were equally favourable for wheat. Blodgett (1857) published his masterpiece on the climate of North America drawing attention to the favourable climate of the Plains north and west of Lake Superior. His comment that spring opens at nearly the same time along the immense line of plains from St. Paul to the Mackenzie River was widely regarded as authoritative. MaCoun (1882) published a book on the

Canadian Northwest in which he predicted a successful wheat crop a short distance from the Hudson Bay.

Recent reconstruction and interpretation of weather and climate in western Canada including seasonal and monthly patterns have drawn heavily from the Archives of the HBC. Allsopp (1977) reviewed the agricultural climate in the Red River basin between 1800 and 1975. Catchpole and several Manitoba researchers have used the archives for several definitive studies of climate in the West and North during the period of european settlement (Catchpole 1980, Catchpole et al 1976, Catchpole and Ball 1981, Moodie 1977, and Rannie 1983 to name a few). Ball (1983) used these archives and the migration pattern of geese for his study of climatic change in the 18th and 19th century in the Southern Hudson Bay Region. Wilson (1982, 1983 and 1985) made extensive use of HBC post records for the study of local and regional climates in the Hudson Bay area including aspects of the Little Ice Age.

5.1.7 *The Churches.* The churches played a vital role in opening up the Canadian interior to settlement and commerce. In Western Canada, the Church Missionary Society began work in 1822 in response to a request from John West, Chaplain to the Hudson Bay Company. Since its main interest was in conversion of the heathen rather than in ministry to British settlers, the society concentrated its work primarily among the Indians and Eskimos of the territory controlled by the Hudson Bay Company. Daily journals kept by these missionaries are good sources of weather data especially when used as a supplement to achieve spatial and temporal completeness. It is equally significant that some of the Colleges founded by churches played a significant role in the collection and archiving of early meteorological data. St. John's College in Winnipeg was home to the first set

of meteorological records used as official data by Canada's Atmospheric Environment Service.

Examples of climate information kept by missionaries include those found in the Ross Papers (Ross, 1853)

> *The heat was very great here (Toronto) during the whole of August – greater than I ever felt at Red River . . . 200 or 300 died of that heat in New York.*
>
> *(James Ross to Alexander Ross on 16th September 1853)*

> *We had snow last week (at Red River) but it is almost all gone – we have beautiful weather at present.*
>
> *(Alexander Ross to James Ross on 4th November 1853)*

Rev. Pettitot (1885) who made a significant contribution to the climate of the Athabasca area through his methodical record of fluctuations of Lake level in the Athabasca Lake, the Stanley Mission diaries at English River (1873, 1874), Rev. Cowley's papers on the missionaries of the Church of England (1843, 1851) and the Morris papers at the Methodist Mission at Whitewash Lake (1876) represent a few of the other useful records on weather and climate left behind by missionaries of that era.. Catchpole (1980) includes records from the files of the Oblates of Mary Immaculate and the Sisters of Charity.

The records of the Church Missionary Society are housed in the National Archives, Ottawa. Those kept by individual missionaries are located in provincial archives in Winnipeg, Saskatoon/Regina and in Edmonton. The Glenbow Museum in Calgary and public libraries in the prairies also house church related documents.

## 5.2 ASSESSING THE QUALITY OF DOCUMENTED SOURCES

Use of written documents for meteorological data must be approached with caution. When referring to extracts dated prior to 14th September 1752, it should be remembered that the present Gregorian calendar was introduced that year thus necessitating the advancement of the Julian calendar then in use by 11 days. This is particularly relevant to those early records of the HBC taken around the Hudson Bay.

The observation procedure used for obtaining the weather data contained in meteorological reports was not always clear. Alexander Henry the Younger meticulously described the methodology used, the type of instrument and its calibration as well as instrumental exposure. The Hudson Bay Company official records were obtained with directives issued by the British Head Office but these procedures were not in place prior to 1814. C.V. Wilson (1982) has outlined a procedure which when used, reduces the pre-1814 temperature data to their modern Stevenson screen equivalent. Meteorological registers such as Ft. Gary and Battleford, the equivalent of modern local weather stations, several of which were unofficially linked to the Toronto observatory and the Smithsonian Institute, generally followed the guidelines issued by the International Meteorological Organisation. However, most of the diaries examined were silent on procedures and one was not always sure how the occasional temperature and snow depth measurements found in them were obtained. Before they can be used for climatic description, data drawn from the latter group should be calibrated against those obtained from surrounding meteorological registers.

The largest group of climatological data came from non-instrumented diary entries. In light of the diverse reporting styles adopted by journal keepers, the conversion of non-numerical meteorological entries found in diaries, especially the personal ones, is bound to be problematical. Where entries are many, and

more or less a daily routine, the reader is able to gain considerable insight into the range of numbers that would normally apply to certain descriptors. Indeed in most official diaries it is fairly easy to recognise when a change in the personnel responsible for the maintenance of the diaries occurred. This is because of the change in "language" and sense of the weather which normally followed. Moodie and Catchpole (1975) applied "content analysis" to transform qualitative to quantitative meteorological data. They contended that the method could yield a high degree of objectivity to the extent that different persons armed with the same set of information would arrive at similar judgement. Catchpole et al (1976) successfully used the methodology for analysing freeze up and break up dates on estuaries on the Hudson Bay based on HBC post records, Baron (1982) reconstructed 18th century temperature records based on similar analysis.

Non instrumented daily diaries and general chronicles on the weather provide quantitative data on frequency of meteorological events including the number of days with precipitation, number of days with sub-freezing temperature, and wind direction. These data are not only useful for frequency and probability modelling of climate at daily, monthly and seasonal levels but can also be utilised upon calibration to reconstruct reasonably accurate interval and ratio data. Nkemdirim (1988) showed the strong relationship which exists between precipitation frequency and precipitation amounts in Calgary despite evidence of an increasing trend in the former variable. Ali and Mawdsley (1987) have shown that wetness frequency can be a good measure of variation of soil moisture even though their attempt to use it for the validation of evaporation models met with mixed results.

One striking feature of non instrumental diaries and chronicles is the emphasis placed on extreme and/or unusual weather. Winds, temperature minima and snow storms were favoured targets. Such entries lend themselves to frequency analysis but several years of such reporting by one individual may be necessary for

reasonable conversion of the qualitative data into quantitative form. However, the task of such conversion even in shorter term records is aided by evidence of the environmental consequences attributed to them – for example: the rise in stream levels, the height of valley and dimensions of farm areas inundated by the effects of heavy rainfall or snowmelt, erosion, and the extent of frost-related crop damage, and the date in which the event occurred. Correlation with data from meteorological registers and corresponding reports kept by neighbours also facilitate conversion.

The dates of first and last frost of the year are good indicators of climatic trends (Nkemdirim and Venkatesan, 1985). Unfortunately, while the first frost in late summer or fall was usually reported in chronicles, the date of the last frost in the spring is not except when it is unusually late e.g. a mid-June occurrence.

The pool from which data can be drawn for climatic reconstruction for the prairies since the post European period is deep. However, to ensure as much accuracy as is potentially possible, a combination of qualitative and numerical data, measured or synthetically derived, with other evidence of the changing weather such as contained in phenological events is recommended.

In many ways the homesteader journals and chronicles added a dimension to the climatic profile of the prairies beyond that contained in trading post journals and in meteorological registers because of the sense of climate and its variability which they convey. They gave a wider spatial coverage to official records, and also provided details on the objective consequences of climatic variability for the land, economic, and environmental resources. These effects, on which the official data was often silent, also constitute proxy data.

# 6. PROXY METEOROLOGICAL DATA FROM PALEOECOLOGY

Paleoecology is defined as the reconstruction of past biota communities and environments. This large envelope includes past flora and fauna, ancient lacustrine and riverine sediments, soils, a variety of geological formations, and more importantly, the interaction among the various components of past environments. The physical and chemical make-up of past environments conceal climatic signals retained at the time of formation. Climatic reconstruction from paleoecological evidence is performed by decoding the hidden signals. The science of paleoclimatology is rooted in the premise that the present is an analogue of the past; i.e. that the ecological and climatic combination which support present populations of fauna and flora and any variability found within them, are identical to those which supported their past equivalents.

Paleoecological evidence of various descriptions found in the prairies and its bordering regions has been used by scholars working in diverse disciplines to interpret past climates of the west. While there is considerable agreement on the broad features of major climatic events, details may diverge and dates may not always coincide. The sources reviewed are:

1. Dendrochronology
2. Palynology
3. Lake sediments and paleohydrology
4. Archeology
5. Multiple sources

## 6.1 DENDROCHRONOLOGY

Dendroclimatology is the reconstruction of the climates of the past from information expressed by some features of tree rings including variations in width, density or isotopic composition (Fritts 1976). Dendrochronology is the

"precise" dating of such features. Fritts (1976) has provided an extensive discussion on tree ring analysis and the sensitivity of the rings to temperature and precipitation. He contends that the most valuable information on precipitation variability is obtained from trees growing in areas where moisture is a critical factor to growth such as arid or semi arid areas. Data on temperature variability are best preserved near either the latitudinal or the elevation limits of the tree specie. Thus the more limiting the climatic signals are, the more discriminating the tree rings would be. "Sensitive" trees produce rings which exhibit sufficient variability to enable climatic interpretation of the pattern of wide and narrow rings found. Trees which do not possess this property are said to be "complacent".

Techniques for recovering climatic and hydrological records from tree ring data include those developed at the Laboratory of Tree-Ring Research at the University of Arizona. These techniques utilise multivariate analysis to correlate tree ring properties with climatic indicators covered by existing historical records. A transfer function is then developed, tested against "a held back" historical data set and used thereafter to recover climatic data from prehistoric dated tree rings (Stockton and Fritts 1971).

The prairies are tree poor except along rivers and around lakes. The cottonwood tree is, however, the predominant specie but is viewed by scientists as the type of vegetation more likely to yield a complacent series.

Jozsa et al. (1984b) and Parker et al. (1977) noted that the oldest trees in Canada suitable for dendroclimatology (i.e. species with well defined annual rings and trees growing near climate-recording stations), are relatively complacent. However, much can be learned about the climate of the prairies from data derived from trees which grew along its margins where trees would normally produce a sensitive series. D'Arrigo and Jacoby (1990) were able to show agreement at least

in phase if not magnitude between recorded and proxy temperature data for Northern North America from 7 tree ring width climatologies obtained in the Northern American Arctic and sub-arctic. The climatic pattern parallels those observed in the prairies. As Wells (1970) pointed out, accumulated evidence indicates that the extensive treeless grassland now occupying the plains of central North America have not had a continuous existence there since the mid-Holocene. An increasing number of pleistocene pollen and macrofossil records have documented the existence of coniferous woodlands or forest vegetation at several sites on the Great Plains from South Dakota and Minnesota, south to Kansas and Western Texas.

Weakly (1965) compiled a drought series for the Great Plains based on tree ring analyses in Nebraska (table 4). He showed that in the last 800 years or so there have been 20 identifiable periods of drought with an average duration of 12.8 years per event, a range of 5 to 26 years and a mean recurrence interval of 23.9 years.

Table 4. Drought series for the Great Plains based on tree-ring analysis in Nebraska

| *No.* | *Approximate Duration From* | *To* | *No.* | *Approximate Duration From* | *To* |
|---|---|---|---|---|---|
| *1.* | 1220 | 1231 | *11.* | 1688 | 1707 |
| *2.* | 1260 | 1272 | *12.* | 1728 | 1732 |
| *3.* | 1383 | 1388 | *13.* | 1761 | 1773 |
| *4.* | 1438 | 1455 | *14.* | 1798 | 1803 |
| *5.* | 1493 | 1498 | *15.* | 1822 | 1832 |
| *6.* | 1512 | 1529 | *16.* | 1858 | 1866 |
| *7.* | 1539 | 1564 | *17.* | 1884 | 1895 |
| *8.* | 1587 | 1605 | *18.* | 1906 | 1913 |
| *9.* | 1626 | 1630 | *19.* | 1931 | 1940 |
| *10.* | 1668 | 1675 | 20. | 1952 | 1957 |

Following the evidence of spatial persistence of droughts in the Great Plains and the prairies in the nineteen thirties (Mackay 1978, Jones 1987, and Smit and Nkemdirim 1990) and in the eighties (Kunkel and Angel 1989), Weakly's series should provide a reasonable approximation of the Canadian prairie drought series. Documented evidence indeed confirms 1858 as a dry year in Southern Alberta (Palliser, 1859). 1826 was dry in the Red River Settlement (Sutherland, 1938) and 1887 was dry in southern Saskatchewan (Trueman, 1887). Mackay's prairie drought series of this century is in broad agreement with the corresponding Weakly series.

Stockton and Fritts (1973) sampled six tree-ring sites within the Peace - Athabasca delta in the northern border of the Canadian prairie. From tree ring data, they were able to extend the then known 33-year record of lake level changes to 158 years. With some reservations on the generality of their conclusions, they pointed to the striking similarities between their reconstructed water levels and climatic trends in the prairies described in Thomas (1965). The following periods were identified: (a) 1837-1848 – drought in the prairies, low lake levels, (b) 1860-1869 – flooding in 1861 and general dry conditions throughout the rest of the decade; high water levels in 1860-1863 and extremely low levels during the rest of the decade, and (c) 1880-1889 – a cold period throughout Canada; especially severe winters at Edmonton; high lake level. The authors noted that not all lines of climatic evidence discussed by Thomas (1965) show such agreement. Several appear to be unrelated to changes in the lake levels, but very few actually contradict.

In addition to reconstructing the general pattern of sequences of wet and dry years. Stockton and Fritts (1973) were able to obtain seasonal fluctuations of water levels, and by implication, seasonal climatic signals from, tree ring analysis.

David Sauchyn at Saskatchewan's University of Regina is reconstructing a 143-year climatic data from present day stands of white spruce and lodge pine in Cypress Hills, Alberta/Saskatchewan. He is finding a significant correlation between annual precipitation and ring width. However, because of the mix between snowmelt and rain during much of the growing season, seasonality in precipitation distribution has not been detected. No significant correlation is known to exist between temperature and ring width since according to Sauchyn, moisture and not temperature is the limiting variable to tree growth in this area (Sauchyn, per. comm.).

Indeed tree ring analysis is most useful when the objective is narrowly targeted to identify temperature and moisture conditions during critical growing periods of a tree specie. Since Parker and Henoch (1971) revealed a significant correlation between density indices and August mean air temperature near Peyto Lake, Alberta, several studies in the prairies have applied densitometric measurement for detecting seasonal variations in climatic signals.

Jozsa et al. (1984a) have outlined the procedure for analysing X-ray densitometric data using samples taken from an old Douglas-fir stand from Banff, Alberta. An x-ray of a core sample is scanned by a densitometer which produces a graphical representation of the density variation within each wood core including ring width, early wood width, late wood width, minimum density and a standardised ring density profile. The resulting data are then subjected to multivariate statistical analyses which enables the recovery of temperature and precipitation data, and their seasonality.

It appears that the success achieved and achievable here rests on the sophisticated numerical preparation of wood volume and density data such that the prospect for a low ratio of climate signal to biological noise is enhanced (Cook, 1986). This and similar procedures have enabled tree ring analyses to be

extended to otherwise complacent trees such as Engleman Spruce (Parker and Henoch, 1971). Jacoby and Cook (1981) used a time series of ring width indices for twenty seven cores of white spruce trees from the Yukon to show the growth response of these trees to summer temperature and other climatic variables including precipitation. The correlations achieved between tree ring indices and various temperature parameters were high enough that the authors were able to obtain temperature data for the past 400 years. The highest correlation was between tree growth and total degree days above 10°C for June and July. A substantial moisture stress when it occurred towards the end of the growing season, was recognisable. They appeared to be close to reconstructing both monthly temperature and potential evapotranspiration from the series.

Robertson and Jozsa (1988) measured fifteen annual tree ring variables by x-ray densitometry for 429 years (1550 - 1978) for 12 increment cores. They used factor analysis to identify six subsets of ring variable principal component scores from which they developed multiple regression equations for transferring tree ring variables into climatic signals. The investigation conducted in Banff, Alberta verified transfer functions for five climatic variables including temperature, degree days, and precipitation and their seasonality. However, they showed that some climatic elements, precipitation for example, did not transfer well in annual series but performed much better when constructed along the critical seasonal growth period, mid summer for example.

Similar results were echoed by Dang and Leiffer (1989) who determined a long term relationship between climate and tree ring growth in black spruce in two peatland sites near Slave Lake, Alberta. It was found that tree ring indices were related to precipitation and temperature especially in the seasonal domain. They found that: (a) tree ring indices were positively correlated with precipitation for June through August of the current year and the 1st and 2nd year previous to the

current year; (b) June - August temperature of the current year was positively correlated with tree ring indices but negatively correlated with those of the 1st and 2nd years prior to the current year; (c) tree ring indices had a positive linear correlation with the June - August minimum temperature of the current year and polynomial correlations with June - August minima of previous one and two years, and (d) summer precipitation values greater than 325 mm probably have a negative impact upon the growth of tree rings.

The value of tree rings as sources for proxy data in the prairies is uncertain. Firstly, there are very few trees in the prairies proper which predate historical record by a sizeable margin, and what trees there are at sites with meteorological stations are probably complacent. Forest stands where they occur in the prairies are patchy. Fritts et al. (1971) have shown that data derived from spatially restricted areas are noisy, a noise which can be controlled in part by averaging over large areas. It follows therefore that reliance has to be placed on proxy data from trees growing in the boreal forest and the slopes of the Rockies. This requires the establishment of a correlation between the climatic signals in the prairies and those of the neighbouring sensitive tree-growing regions and subsequent reduction of the forest proxy data to its prairie temporal equivalent. In light of the considerable noise encountered in tree-ring analysis in a field in which the explained variance between tree ring variables and climatic signals of less than 60 percent is hailed as excellent, it is doubtful that this two stage approach will represent a significant improvement on other prairie based paleoclimatic data.

The use of multiple measurement on tree rings including density and isotopic composition and the availability of high speed computers have enhanced the promise of the rings as tools for climatic interpretation. This promise is particularly exciting for the reconstruction of shorter term data such as seasonal

averages. The fact that efforts are now being directed toward time domains as small as 3 days during critical stages in the growth cycle of trees suggests that we may yet obtain a useable daily series from tree ring data, at least for critical growth periods.

There is to the knowledge of this writer, no study directly aimed at soil moisture cross dating from tree ring analysis. This neglect might be due to the absence of long term soil moisture data from the weather records used in establishing chronologies.

Some of the urgency for a direct correlation of soil moisture and tree rings is removed by the explicit reconstruction of precipitation and temperature trends which impact directly on soil moisture. Because most tree ring climatic reconstructions are generalisations of average weather over large regional units where local advantages such as access to perched ground water is not at issue, a regional water balance accounting could be performed with soil moisture evaluated as a residual. This would require in addition to temperature and precipitation, knowledge of soil type and depth as well as evaporation rates. That this can be done is demonstrated by Stockton and Meko (1975) and Meko et al. (1980) who constructed a drought series for the Western United States based on tree ring data and the Palmer Drought Severity Index, the latter variable requiring explicit expression of soil moisture and evaporation.

In light of what has been said about the relatively low precision of tree-ring reconstituted climatic data, it is difficult to imagine that water balance determined soil moisture will be any more precise. Further development in this area should await the direct introduction of soil moisture as one of the multiple variables used in determining eigenvectors in tree ring climate models.

Finally, the caution of Wallen (1963) is worth repeating:

> *One of the several problems with this method (dendrochronology) is that it is often difficult or impossible to be sure which of the climatic factor that has caused the ancient fluctuations in the density of the rings. In certain parts of the world it may be possible to find out by modern methods of correlation which factor in recent times has played the most important role in the development of trees, but this does not necessarily mean that the same factor was predominant in ancient times . . . in applying dendrochronology to ancient periods it is valuable if results are supported by evidence pointing in the same direction but derived by geomorphological, pollen analysis, archaeological or other methods.*

The same words of caution should be applied to any method of climatic reconstitution based on paleoecological evidence. Convergence of two or several sets of evidence would normally improve confidence in conclusions reached. Divergence would point to a need for further investigation.

## 6.2 PALYNOLOGICALLY-BASED RECONSTRUCTION

Palynology or pollen analysis is perhaps the best known and most widely used method for biotic reconstruction. Because of the direct relationship between climax vegetation and climate, palynology has proved itself as an effective tool for paleoclimatic reconstruction.

Pollen analysis is based on the fact that the vegetational composition of a given area for a given year is preserved in the pollen rain falling in that year. The relative abundance of each plant family group and even species within the family provides clues about the climate which supported the vegetation mix. Pollen is best preserved in bogs, swamps, lake beds and similar environments in which poor aeration ensures the preservation of sufficient quantities of the annual pollen yield. The pollen profile extracted from a core sample can be used to construct a

temporal chronology of vegetation and from this the climate. Modern $C_{14}$ is normally used to date the horizons used for profile (spectrum) building. Faegri (1975), Wijmstra (1978) have discussed many of the problems associated with pollen analyses. Reference should be made to their work before this approach is adopted as a source for proxy data.

However, unlike tree rings, palynology is only able to give broad generalisations on climatic patterns. It can provide clues on low frequency climatic change – those that occur over decades or a few centuries – but is almost incapable of reproducing high frequency changes in the annual or seasonal domain. In the words of Ritchie (1989) "pollen data record with reasonable accuracy long term changes in vegetation – that is changes in specie composition registered over time intervals of hundreds and thousand years".

Recently, however, efforts are being directed towards shorter time resolution. Ritchie and Gajewski (1986) reported that pollen deposited in the past 10-20 years is being collected from a series of 2000 lakes across North America including 50 in Western Canada. At each site, the modern pollen rain is being correlated against present day climatic normals. For those sites where climatic data are either absent or inadequate, the programme includes the gathering of weather data which will be used in time to obtain normals. Regression equations are developed which relate the present day climate to the present day pollen. These regression equations are then applied to fossil data to derive a time series of the climate of the past for sites. The method is being extended to the reconstruction of seasonal temperatures. Ritchie (1983a) derived a time series of May - August mean temperature from Riding Mountain Lake in Southern Manitoba. His results show that while active growing season temperatures can be recovered from pollen data, the time resolution remains coarse, in the 1000 year scale.

Ritchie (1983b) summarised the paleoclimate of Canada's central area as follows:

- 13000 to 10000 B.P., a cool climate with summer temperatures in the northern Lake Agassiz basin between 5° to 10°C (mean July temperature 10° to 15°C) supporting a spruce forest on mesic sites with abundant poplar and willow stands on alluvial and hydric sites, and open shrub.

- 10000 to 6500 B.P., a warm dry climate with summer temperatures 15° to 17°C (mean July temperature 18° to 21°) and effective precipitation 10 to 20% less than modern values, supported a prairie zone complex of communities on all sites except hydric and cool-mesic, where shrub and deciduous tree stands prevailed.

- 6500 to 3000 B.P., a warm climate with summer temperature similar to the preceding intervals, but greater effective precipitation supporting a mesic of grassland and woodland communities.

- 2500 B.P., the establishment of the modern climate and vegetation.

Details may vary from region to region and from site to site but this scheme appears broad enough to fit most climatic shifts unearthed for most parts of the prairies in late Wisconsin and the Holocene.

Dean et al. (1984) summarised climatic trends in Western North America during the Holocene based on pollen data:

> *The climate model that has been developed (for the Holocene) is one of gradual increases in warmth and dryness from early to middle Holocene time (Hypsithermal interval, climatic optimum or thermal maximum), followed by a gradual decrease to more or less present conditions in the late Holocene time.*

> *Superimposed on the general trend, particularly in the Midwest of North American, are two dry pulses separated by a moister interval in Mid-Holocene time.*

Anderson et al. (1989) reviewed the time-space migration of the prairies during the early Holocene:

> *Early spruce forest gave way to prairie grassland by 10000 B.P. at Herbert, 10600 B.P. at Hafichuck in Southern Saskatchewan, 10,000 B.P. at Russel in Southern Manitoba and slightly later 9500 B.P. to the north. The replacement of spruce by grassland in the southern part of Manitoba and Saskatchewan is attributed to a warmer drier climate supported by an increase in frequency of fires. Warm, dry conditions apparently peaked between 8000 and 6000 B.P. resulting in the expansion of prairie vegetation beyond its present range and reduction in water levels in some of the more southerly lakes. This interval of maximum warmth correlates with prairie expansion in the Midwest U.S. and the beginning of the prairie peninsular as a discrete floristic area in Illinois (King, 1981).*

More specific gradual warming occurred from 10000 to 8000 B.P. Rapid warming followed after 8000 with temperatures reaching a maximum near 4000 B.P. at which time the mean annual temperature was about 2.5° above present. This persisted until 1000 to 1500 B.P. although marked by gradual deterioration. Ritchie and de Vries (1964), Ritchie (1976), Christiansen (1979) and M.A. Wilson (1982) provide pollen data for the prairies which fit the pattern given above. Southern Manitoba in particular was an area of considerable early pollen work by Ritchie (1964, 1967) and Ritchie and Lichti-Federovich (1968). Nambudiri and Shay's reconstruction of Holocene climate in Lake Manitoba is also consistent with the sequence of events reported by others (Nambudiri and Shay, 1986). Ashworth and Cvancara (1983) used the expansion of deciduous forest and white

pine into areas formerly occupied by prairie and Oak Savanna to show that the climate was cooler and wetter in the southern part of Lake Agassiz between 4000 BP and the present. Ritchie (1976), Christiansen (1979) and M.A. Wilson (1982) did similar pioneering work in Saskatchewan. Early pollen work in Alberta was carried out by Hansen (1949, 1952), Moss (1955) and Stalker and Mott (1972). Detailed pollen studies in Central Alberta confirm a period of persistent aridity beginning as early as 9200 B.P. and terminating by 5800 B.P. or slightly later (Lichti-Federovich, 1970; Vance 1986 and Vance et al., 1983). At the peak of the Holocene arid period, deep lakes in Central Alberta became shallow saline ponds, some supporting ditch grass, while shallow ponds dried to salty pans covered with glassworth. The Holocene climatic optimum in the prairies is also indicated by Schweger and Hickman (1980, 1989; Hopkins 1972). Climate deterioration to present condition began sometime after 4000 to 3000 B.P. (Ritchie, 1972). Kearney and Luckman (1979) presented pollen data obtained near the Continental Divide in Alberta. They suggest that the hypsithermal interval had two warmer phases separated by a cooler period between 8000 and 7500 B.P. Both authors also showed that the timberlines in Alberta Rockies were much higher during the hypsithermal than at present (Kearney and Luckman 1983). MacDonald (1982) indicated from pollen evidence that the vegetation of southwestern Alberta has remained stable since c. 9395 B.P. He opined that an increase in abundance of pine and spruce in mid-Holocene would suggest climatic improvement. The Chalmers bog site in southwest Alberta shows a simple major change at the beginning of the Holocene, from a treeless arid landscape to an assemblage dominated by pine and spruce that has remained unaltered to the present day (Ritchie 1984).

Pollen data have also been used to map the fluctuation of the mean position of the Arctic Front. Ritchie and Hare (1971) determined that the summer position of

the Arctic Front was displaced about 350 km further north of its present position during the height of the hypsithermal. Hare (1973 and 1976) believed that the tree line and other vegetation boundaries in Canada's north followed the Arctic Front. A recent study by Scott et al. (1988) confirmed Hare's opinion.

As noted by Schweger and Hickman (1989), a south western surface wind off the retreating Laurentide Ice Sheet has been hypothesised to explain sand dune orientation in Saskatchewan (David 1981), the rapidity of spruce colonisation into northwest Canada (MacDonald and Ritchie, 1986), and early to mid-Holocene climatic changes in Alberta (Vance 1987; White and Matthews, 1986). Kutzbach and Guetter's simulation of surface wind for 9000 B.P. did not reveal the possible presence of these winds (Kutzbach and Guetter 1986).

While there is broad agreement on the sequence of major phases of Holocene climates, similar agreement on details is frequently lacking. Disagreement has centred around three major themes, namely, progressive and continuous succession, local environmental impact, and rapidity of vegetational response to climatic change. Mott (1973) cites well-documented examples of abrupt transition from one vegetation type to another in the Riding Mountains uplands of Manitoba where an early Holocene spruce-dominated phase was replaced abruptly by a grassland episode that persisted from 10000 B.P. to 6000 B.P. Progressive succession is also disputed. Local conditions could result in an abrupt change in colonisation which might not reflect an equivalent monocline in climate. These types of argument have led Mott and Jackson(1982) to conclude that several quite different pathways of vegetation change have occurred in the past preceding the modern boreal forest. In their opinion, the older view that plant or biomass formation migrate in response to climate change as propagated by authors such as Pielou (1979) is not applicable to the boreal forest, if to any formation. They also dispute the concept of a cohesive boreal forest past and present, which follows a

coenocline in which the composition and abundance of plant population vary continuously along environmental gradients (Whittaker 1975). In some cases no major environmental change is found and vegetation may be site specific. The rapidity and magnitude of vegetational response to climatic change can vary tremendously in both time and space as can composition and dynamics (M.B. Davis 1984). Webb (1986) discussed the limitations of the concept of an equilibrium between vegetation and climate. Wright (1976, 1984) noted that the hypsithermal interval in the prairies was time transgressive, a view consistent with Bernabo and Webb (1977) who had mapped the changing pattern of pollen records of the Holocene in the American northwest.

In conclusion, palynology is a very powerful tool for climatic reconstruction. However, the time lines drawn are too coarse for the reconstruction of yearly temperature and precipitation. Seasonality can be inferred but only on a time scale of several decades. Monthly and daily data are not recoverable at present. The use of multivariate statistical methods and high speed computers will no doubt improve the capacity to analyse and evaluate numerous samples and variables simultaneously following the trend now occurring in dendrochronology. By eliminating the intermediate step of vegetation reconstruction, synecology has made it possible to reconstruct paleoclimates directly from pollen data. These developments could in time produce a methodology capable of recovering higher frequency data not only on traditional climate variables such as temperature and precipitation, but also on other desirable ones including soil moisture and evapotranspiration from pollen.

## 6.3 LAKE SEDIMENTS AND OTHER PALEOHYDROLOGICAL EVIDENCE

Delorme (1986) describes the principles and methodology behind the use of lake sediments for paleoclimatological interpretation. Most parts of the world

including the prairies have an abundance of lakes and ponds. These basins collect sediment and support various types of organisms. When the organisms die and conditions are right; some remains, such as shells and skeletons, may be left behind as fossils incased in the sediment. Such fossils may be recovered when a core sample of the sediment is drawn. Given a time frame for the core and the known ecological data for fossils of crustaceans (such as ostracodes) found within the sediment, horizons within which the fossils are found can be dated and the climatic data of the environment in which they were supported recovered. Data on temperature, mean annual precipitation and even evapotranspiration rates can be obtained.

Like palynology and dendrochronology, the present is key to the past, the so-called principle of uniformity. We assume that the mix of climate and environmental parameters which determine the relative abundance of the organisms today was the same as those which supported them in the past. Delorme (1986) noted that climatic change can only be determined by processing many core samples which represent decades or hundreds of years. Changes are sought in the magnitude of an individual climatic signal. When this same point of change occurs in many other signals, it is considered significant. The cause of the change is then searched for.

Water levels in inland lakes without outlet rise and fall in response to climate (Laycock, 1973). High water levels are associated with a wet climate and low levels with a dry one. However, the lake level fluctuation is also a function of temperature and wind driven evaporation. Thus high lake levels could occur if a relatively dry weather is also cool. Wet and hot weather could also cause a low water level especially in humid environments (Grove et al., 1975). Stockton and Fritts (1973) cite one example in Athabasca Lake where a rise in water level was due more to a drop in temperature than to an increase in precipitation. It is

unlikely, however, that this type of effect will show up consistently in multiple samples on which reconstruction is normally based unless it actually occurred. It is suggested when using lake levels for climatic reconstruction that independently derived evidence from other sources be examined for convergence.

Past lake levels are identified by the strandlines and overflow channels they created as well as by the depositional history associated with them. Fossils of flora and fauna preserved in them, especially if these are local rather than transported, aid the interpretation process.

Lake Agassiz, a glacial lake created about 13000-12000 B.P. when the Laurentide ice sheet blocked the natural drainage to the east and north, covered a huge area of central North America including the eastern prairies, large portions of Manitoba, Saskatchewan, Northwestern Ontario, North Dakota and Minnesota. It even extended to the Arctic Northwest. The lake level dropped steadily after 9500 B.P. until its final drainage into the Hudson Bay around 8000 B.P. (Nielson et al., 1988). Lake Agassiz's, residual beaches and lakes, for example, Lake Manitoba have provided excellent opportunities for lake level based climatic reconstruction (Teller and Clayton, 1983).

From c. 9000 to 4500 B.P., the level of Lake Manitoba fluctuated in response to climate and differential isostatic rebound (Teller and Last, 1979, 1981). This period was marked by several episodes of drought. The dry condition came to an end about 4500 B.P. when, due in part to increased wetness,the Assiniboine River was diverted into the lake's watershed. The river was diverted out of the basin about 2200 B.P. and water levels in the southern part of the lake have remained relatively constant since then, mainly because of a gradual shift towards a cooler, wetter climate. Dredge and Nielson (1985, 1987), Nielsen and Dredge (1982) and Dredge and Cowan (1989) have used aspects of the fluctuations in the Agassiz lake level in their interpretation of climatic and sedimentary history in Manitoba.

Based on evidence from paleochannels in the Assiniboine river, Rannie et al. (1989) contend that there may not be a direct link between channel forming discharges and sediment load of ancestral rivers, and climatic change during the Holocene.

Schweger and Hickman (1989) used paleohydrological records from 28 lakes and bogs to reconstruct paleoclimatic history for central Alberta. Shallow basins, emptying during the early Holocene, began flooding shortly after 8000 B.P.; most filled from 6500 to 4500 B.P., and none filled later than 3000 B.P. They used their findings to interpret the post glacial climate in this area indicating an early Holocene aridity, the onset and development of moister conditions between 8000 and 3000 B.P., by which time modern climatic and vegetation conditions had been established. Schweger et al. (1981), White and Mathewes (1982, 1986), Hickman et al (1984) and Hickman (1987) provided evidence of increased evaporation stress on vegetation during the early Holocene in the Peace River district of Alberta based on lake core studies. Vance and Mathewes (per. comm.) are currently investigating pollen, plant macrofossils and sediment chemistry of five core sections from the Chappice Lake basin in the arid southern Alberta grassland. The objective is to reconstruct relatively recent lake level fluctuations as a proxy record of prehistoric drought. They have identified two major periods of droughts, the first between AD 1700 to 1900 and the other between AD 800 to 1400. These drought periods fall within the Little Ice Age and the Medieval warm period respectively. They hope to be able to construct a chronology of drought events over the last millenia by the time the project ends.

Delorme (1966) reconstructed pleistocene and past pleistocene environments in Saskatchewan from Ostracodes. Froese (1956) discussed metamorphosed sediments of Middle Foster Lake Saskatchewan and Miuni (1969) the prehistory of Black Lake Saskatchewan.

Lake sediments offer a very promising environment for climatic reconstruction for the prairies. However, as several authors have noted, basal data in most parts of the prairies especially the south, do not go back far enough to enable the reconstruction of climates during large portions of the Holocene. M.A. Wilson (1982) has attributed this state in part to prairie droughts which desiccated many potentially suitable sites. But even if suitable sites were abundant it is doubtful that sediment-derived climatic data will enhance the prospect for obtaining annual, seasonal and monthly temperature and precipitation data for the prehistorical period. As Wallen (1963) points out, geological and pedological evidence left behind in the dried up lakes do not give us any idea of the order of magnitude of a climatic change; neither as far as the fluctuation of the climatic elements is concerned nor the area covered by the change.

## 6.4 ARCHAEOLOGICAL SOURCES

Archaeology, the scientific study of the life and culture of ancient people based on the excavation of ancient cities, relics, artifacts and the like, is rapidly gaining respectability as a paleoclimatic reconstruction tool. Humans and animals are bonded to the environment. Quite often and especially in the semi-humid or semi-arid parts of the world where ancient cultures flourished, changes in vegetation and agricultural conditions are used to prove the existence of climatic fluctuations during a period studied by archaeological methods. However, changes in vegetation and agricultural habits are themselves often a result of the influence of humans, and therefore great care should be taken in interpreting such changes as those caused by climatic influences.

Lamb (1977) has compiled aspects of human occupancy of the land which might lead to inference of changing climates. These include: (a) latitudinal and altitudinal limits of settlement, cultivation and seasonal pastures, (b) population

abundance and migration patterns, (c) landuse changes, (d) morbidity and mortality of humans and animals, (e) characteristics recorded in art, architecture, tools and industry. Lamb (1977) emphasised the need for archaeological evidence to be collaborated by other types of evidence before being used with confidence in climatic interpretation. Archeology does not employ the scientific method of hypothesis testing and prediction. Archaeologists excavate promising sites, then analyse and interpret what they find in light of the evidence (Bryson and Murray, 1977).

Bryson and Murray (1977) examined the Mile Creek Culture of Iowa in the context of a changing climate. The following quote illustrates the nature of the relationship between the land and the people living on it, and its climatic implication:

> *That area today averages 25 inches of precipitation. Generally it produces corn and soybean, but rainfall is not always enough to compensate for hot summer winds, and agriculture is frequently moisture limited. A drop of 25% or more in moisture will show up dramatically in corn fields. It would also show up in the hunting and agricultural economy of Mill Creek people. Refuse of their diets would reflect a drought, as would the pollen scattered by plants growing 800 years ago.*

The diet of animals recovered from refuse or from fossil bones can be used as a tool for climatic reconstruction. Barnes et al. (1983) and Looman (1983) have discussed the relative abundance of $C_4$ and $C_3$ plants in a grassland environment and their dependence on moisture and temperature. In $C_4$ plants (e.g. crab grass), $CO_2$ is fixed faster and at lower levels to maximise the gradients of $CO_2$ between the cells and the ambient atmosphere. It follows that when the stomata are open more $CO_2$ is taken up in these plants than when they are open in $C_3$ plants (e.g. blue grass) for the equivalent length of time. Therefore, when a plant

is conserving water (hot, dry climate), $C_4$ plants will be at an advantage. Since bisons are indiscriminate grazers living on whatever pasture is available to them, a diet rich in $C_4$ plants would indicate a warm dry climate, whereas the opposite will be true in moister and cooler environments. The abundance of $C_4$ and $C_3$ plants in the diet of animals could therefore be used to calibrate changing moisture and temperature conditions. Coupland (1958) has discussed the effects of fluctuations in weather upon the grasslands of the Great Plains. Eleringer (1978) showed the significance of other environmental factors on yields of $C_3$ and $C_4$ plants but moisture and temperature were still the dominant variables.

McKinnon (1987) used the known behaviour of American bisons including the lack of discrimination of the type of grass ingested (McHugh, 1958; Chisolm et al., 1986) along with the relative abundance of $C_3$ and $C_4$ grasses in bison diet to obtain a mid to late Holocene climatic profile for southern Alberta. He reconstructed three major periods of drought, the most prolonged being the Sub-Boreal (5250-2750 B.P.) and three prolonged warm periods. The Sub-Boreal was warm and dry, but the warmth and aridity of much of this period were considerably less intense than those of the early Holocene. Temperature was within 1°C of present normal and precipitation was no more than 5 mm lower.

The lack of archaeological materials on the northern plains of Alberta before 5000 B.P. has been used by Reeves (1973) to indicate a mid-Holocene Altithermal. This is collaborated the work by Antevs (1955) but other types of evidence including paleohydrological data do not support the idea of Altithermal (Schweger and Hickman, 1989; Schweger, 1984).

Pettipas (1975) established a relationship between prehistoric droughts and population redistribution in the northern plains. He also reviewed several aspects of human adaptation to the environment in Manitoba including paleo-Indian prehistory in the Glacial Lake Agassiz region (Pettipas and Buchner, 1983), and in

the Parkland belt (Pettipas, 1976, 1981). His review of the paleo-Indians of Manitoba provides a backdrop on the relationship between early people and changing environments (Pettipas, 1975). Mayer-Oakes (1966b) concluded from remains of flora and fauna that the climate of Manitoba between 1150 and 1750 A.D. was not very different from present. Epp (1982) found evidence which supports his view that there were no major dramatic changes in the Saskatoon environment during the period of prehistoric human occupance. Forsman (1987), Prentice (1983), Miuni (1969) and Brougham (1966) present a variety of archaeological and anthropological studies which could serve as sources for proxy data for Saskatchewan. Linuame and Jones (1982) used archaeological evidence of human occupancy of the Saskatoon area to confirm a post-glacial climatic sequence similar in many respects to that proposed by Wilson (1981).

## 6.5 OTHER PALEOCLIMATIC INDICATORS

Paleosols, geomorphology, paleontology, and geology have been used individually or in some combination to retrieve ancient climatic data. Sorenson et al. (1971) used paleosols and radiocarbon dated charcoal from buried surface horizons of soil to obtain evidence of a northward shift of present climate boundaries in North America following deglaciation. Jungerius (1969) utilised evidence from buried soils to reconstruct the fluctuation of post-glacial tree-lines in Alberta. The major conclusion of his study was that the period 4300 to 3600 B.P. was somewhat more humid in the Cypress Hills area than it is today. This was followed by a period of increasing aridity. Harris (1985) used evidence of ash deposition along with other pieces of paleogeographical data obtained in the Foothills and High Plains of Alberta to reconstruct a post-glacial climate sequence in that area. Maximum precipitation occurred about 11000 to 10000 B.P. This precipitation maximum, which more than offset the effects of the hypsithermal

interval in this area, persisted until after the deposition of the Mazama ash. Thereafter conditions became drier. A single short cold spell may have occurred about 8800 B.P. Harris believed that grass spread to its maximum extent by about 7000 B.P. following the abrupt rise in temperature and reduced precipitation which occurred about 10000 B.P. Reider et al. (1988) used soil evidence to prove a climatic and biotic change from dry to humid conditions in northwestern Wyoming between 5400 and 4400 B.P..

Elias (1985) recovered a small insect fossil assemblage from Late Pleistocene lake sediment below the Mount St. Helen's ash near Marais Pass, Montana. The insect fauna contain several arctic, alpine and open ground beetles. This fauna in conjunction with plant macrofossils suggests that at about 11400 B.P. the tree line was at least 450 m lower than present. Carrera et al. (1986) working in the same area used pollen and plant macrofossils recovered from the site to confirm the cooler climate explanation offered by Elias for the lower displacement of the tree line. Nielsen et al. (1987) used the appearance of a woolly mammoth in the Hudson Bay lowlands to suggest the existence of a boreal steppe or steppe-tundra environment during the Early Wisconsonian period.

## 7. SPATIAL, TEMPORAL AND DATA ADEQUACY

### 7.1 SPATIAL COMPLETENESS

In terms of the ability to recover historic and prehistoric data from proxy sources, the prairie region is not homogeneous. Several factors contribute to this situation, among them differences in the timing and pattern of European settlement, lack of suitable sites for paleoecological exploration ,and low research interest.

7.1.1 *Historical Records.* The fur trade in Canada provided the principal motivation for the exploration of the interior of the prairies. Although French traders had made several forays into the prairies between 1600 and 1700, it was not until the Hudson's Bay Company began to build posts on Hudson Bay and James Bay that systematic records of western climate started. The eastern Prairies profited most from the activities of the Company as well as by the presence of settlements such as that at Red River. The climate of Manitoba, especially the north, east and south can be reasonably reconstructed from diaries of explorers, and settlers, as well as trading post journals from about 1700 to 1850. Records from settlements and trading posts established around Lake Superior both in Canada and the United States may be used to extend the data back to about 1680.

Trading posts and settlements spread northwestwards and westwards from the Manitoba beachhead. By about 1780, there was a significant number of settlers and posts in northern and central Saskatchewan to yield proxy data which, combined with the Manitoban experience, could enable one to draw a climatic picture of the prairies. The dominance of interest in Manitoba and the westwards spread of that interest is demonstrated by the number of land surveys.

Table 5. Frequency data on survey records preserved in provincial archives 1869-1899

| *Date* | *Manitoba* | *Saskatchewan* | *Alberta* |
|---|---|---|---|
| 1869 - 1879 | 77 (100%) | 0 (0%) | 0 (0%) |
| 1880 - 1889 | 47 (24%) | 81 (41%) | 70 (35%) |
| 1890 - 1899 | 49 (47%) | 17 (16%) | 38 (37%) |

(Based on data compiled by Catchpole, 1980)

Table 6. Approximate beginnings of continuous proxy data given by region and expressed as a percentage of total data.

| *Area* | *Approximate Opening Date* | | *Proportion of data sources belonging to area (%)* |
|---|---|---|---|
| ***Manitoba*** | | | |
| North | 1700 | | 8.3 |
| Central | 1741 | | 6.9 |
| South East | 1812 | | 22.2 |
| South West | 1795 | | 9.7 |
| | | Proportion for Manitoba | 47% |
| ***Saskatchewan*** | | | |
| North | 1800 | | 6.9 |
| Central | 1795 | | 22.2 |
| South East | 1800 | | 5.5 |
| South West | 1850 | | 1.3 |
| | | Proportion for Saskatchewan | 35.9% |
| ***Alberta*** | | | |
| North | 1800 | | 4.2 |
| Central | 1812 | | 10.3 |
| South East | 1800 | | 1.3 |
| South West | 1832 | | 1.3 |
| | | Proportion for Alberta | 17.1% |

*Source*: Literature survey conducted by the author.

Significant post and settlement activity did not occur in Alberta much before 1800. Posts spread southwards from the North; the Athabasca area was well known by the turn of the century.

Table 6 shows a breakdown of the proportion of documented sources for proxy data for various parts of the prairies and the approximate date for what is believed to be the beginning of continuously maintained data within each area. Manitoba with 47% of all sources located has the most numerous records. Alberta has the least. The Central parts of the provinces which are the northern limit of the prairie proper are the best represented, partly due to their strategic location in the fur trade. The grassland region of the prairies is poorly represented except

in Manitoba. Early unfavourable reports on the agricultural potential of the area and a lack of significant fur trade base conspired to relegate this area to the backwaters.

7.1.2 *Prehistoric Records.* Hills and Sangster (1980) provided a resume of paleobotanical studies dealing with the past 20,000 years in Canada, Alaska and Greenland. They located 366 study sites on maps showing areas of concentration and others where data is poor. Forty-eight of these sites are in the prairies. Fifty-two percent are in Alberta, twenty-one percent in Saskatchewan and twenty-seven percent in Manitoba. An updated version which includes all paleoecological references spotted in the literature is tabulated in table 7.

Table 7. Proportion of paleoenvironmental sources for proxy meteorological data

| *Type* | *Province* | *Proportion of Sources (%)* |
|---|---|---|
| ***Dendrochronology*** | Manitoba | 12.3 |
| | Saskatchewan | 6.2 |
| | Alberta | 82.5 |
| ***Palynology and Paleontology*** | Manitoba | 32.1 |
| | Saskatchewan | 17.8 |
| | Alberta | 50.1 |
| ***Lake Sediments Paleohydrology*** | Manitoba | 42 |
| | Saskatchewan | 10.5 |
| | Alberta | 47.5 |

*Source:* Literature survey conducted by the author.

Wilson (1982) explains the paucity of paleoenvironmental evidence for Saskatchewan as follows:

> *Under suitable conditions pollen and spores can be preserved in vast numbers of sedimentary sequences. Unfortunately, because of the arid conditions prevailing upon the Great Plains, most lakes and sloughs are*

> *ephemeral bodies of water, especially when considered within the post glacial time frame. Given these conditions pollen and spores, because of their susceptibility to degradation by oxidation, are rarely preserved in sufficient quantity to warrant extensive study. Consequently, few studies have been made within the province of Saskatchewan.*

Whereas the reasons for lack of proxy data are valid for the southern prairies (including parts of Alberta and Manitoba), in the northern parts of Saskatchewan where there are trees and less ephemeral water bodies, paleoclimatic reconstruction is still rare. A search of all graduate student theses at both the University of Saskatchewan and the University of Regina did not turn up a single dendrochronological study. Archaeological and paleoanthropological proxy data are also less abundant than in Alberta and Manitoba. However, efforts such as the Nipawin Reservoir Heritage study, the Estavan-Souris River Lake and river sediment project led by Tom Shay of the University of Manitoba, and a number of graduate student projects at the Gowen and Norby sites in the Saskatoon area supervised by Dr. E. Walker, all aimed at building up a paleoenvironmental sequence in Saskatchewan, point to a growing interest in paleoclimatic research in Saskatchewan.

Manitoba has been well served in this area for two major reasons. Firstly, the formation and drainage of Lake Agassiz are two of the major events in Canadian Quaternary history. Sedimentary deposits, and fossils of fauna and flora associated with them, have provoked scientific interest. Two books dealing with Lake Agassiz brought together some of the best minds in Canadian Quaternary studies – Land Life and Water (Mayer-Oakes, 1966a) and Glacial Lake Agassiz (Teller and Clayton 1983) – to bear on this extremely important landscape history. There are also apparently more sites in Manitoba where fossils of pollen and plant macrofossils were preserved than in Saskatchewan. Secondly, the mix of

vegetation especially to the north and east include species which are dendrochronologically sensitive.

Alberta has a number of natural advantages which have aided postglacial climatic reconstruction in the province: (a) the Alpine environment to the West has produced trees which are suitable for tree ring analysis. Plant and insect fossils found in the mountains and foothills have also been useful for interpreting shifts both in the snow and tree lines. Such changes have been invaluable in the interpretation of Holocene climates; (b) the sediments of Central Alberta lakes have been particularly profitable for paleoclimatic work. In southern Alberta some success has been achieved but basal dates are restricted to the late Holocene; (c) there appears to be more persons working on paleoclimatology perhaps due to the fact that two of Alberta's Universities (Alberta and Calgary) have well-developed programmes on such studies, and also because of the oil industry's interest in sedimentology.

## 7.2 TEMPORAL COMPLETENESS

7.2.1 *Historical Records.* The temporal completeness of historical records parallels their spatial equivalent because of its correspondence with trading and settlement activities in the west (see table 5). Tables 7 and 8 taken from Catchpole (1980) present lists of meteorological journals kept at HBC posts but now housed in Winnipeg and London respectively. The founding of Cumberland House in 1774 appears to mark the beginning of continuous weather reporting in the prairies. From that date on there was always a record of the weather in some area of the prairie. By 1785 there were at least 45 post journals. Although several disappeared between 1800 and 1820, the number remained more or less at that high level until 1870 when they declined to about 20. By 1870, standardised weather data were now being collected in many parts of the prairies.

Table 8. Meteorological journals contained in post journals in the Hudson's Bay Company Archives (except where otherwise indicated, each meteorological journal is contained in the post journal of the same name).

| *Location* | *Years* |
|---|---|
| Brandon House[1] | 1814-1815 |
| Chesterfield House (Bow River) | 1800-1801; 1801-1802 |
| Cumberland House | 1806-1807; 1815-1816; 1832-1833; 1839-1840 |
| Fort Chipewyan[2] | 1840 |
| Fort Churchill | 1837-1839; 1838-1839; 1840-1841; 1841-1842; 1842-1843; 1843-1844; 1844-1845 |
| Fort George (Big River) | 1816-1817; 1817-1818 |
| Fort Norman | 1861-1862 |
| Peel River[3] | 1862-1867 |
| York Factory | 1771-1772; 1794-1795; 1829-1830; 1831-1832; 1847-1849; 1850-1851; 1851-1852 |

[1]The Brandon House meteorological observations are continued in the post journal from Winnipeg, 1814-1815.

[2]The Fort Chipewyan meteorological journals is contained in the post journal from Fort Good Hope, 1840-1841.

[3]The Peel River meteorological journal is contained in the post journals from Fort Norman, 1861-1867.

*(After Catchpole, 1980)*

Table 9. Meteorological journals from Hudson's Bay Company posts, preserved in the library of The Royal Society, London.

| *Post* | *Duration* | *Post* | *Duration* |
|---|---|---|---|
| Albany | 1776-1782 | Henley House | 1784-1788 |
| Athapascow | 1790-1792 | Hoffenthal | 1782-1786 |
| Athapascow Lake | 1803-1804 | Ile à la Cross | 1809-1811 |
| Buckingham House | 1796-1797 | Moose | 1795-1797 |
| Carlton House | 1795-1796 | Nain | 1777-1786 |
| Chesterfield House | 1801-1802 | Nottingham | 1805-1806 |
| Churchill Factory | 1792-1793 | Okkak | 1777-1784 |
| Clapham House | 1808-1809 | Reed Lake House | 1794-1795 |
| Cumberland House1 | 1778-1790 | Swan River | 1807-1808 |
| | 1806-1807 | York Factory | 1766-1767 |
| Eastmain | 1777-1781 | | 1771-1772 |
| Gloucester House | 1781-1782 | | 1774-1778 |
| | | | 1793-1797 |

*(After Catchpole, 1980)*

Records from the Bayside and Lake Superior could be used, if calibrated to prairie normals, to extend prairie climate records to late 17th century. It is concluded therefore that about 300 years of documented weather data exist in the prairies.

7.2.2 *Prehistorical Records.* A review of 171 paleobotanical research studies in the prairies and the Northwest Territories provided the proportional breakdown of basal dates for the paleoclimates reconstructed (Table 10).

Table 10. Proportion of periods covered by paleobotanical data based on 171 reference works on the Prairies and the Northwest Territories

| *Dates (Yr. B.P.)* | *% of Surveyed Material* |
|---|---|
| Over 10000 | 16.3 |
| 10000-8000 | 11.1 |
| 8000-6000 | 11.6 |
| 6000-4000 | 26.3 |
| 4000-2000 | 19.9 |
| Less than 2000 | 14.6 |

*Source.* The author.

The mid to late Holocene, with just slightly more than 60% of the data, is the most studied period. The last 2000 years is not adequately represented with a share of less than 15% of the total data. However, dendrochronological data which almost exclusively belong to the last 1000 years and later augment the data base for the near present.

## 7.3 DATA ADEQUACY

7.3.1 *Historical Data.* The major characteristics of historical documents as proxy sources for meteorological data are summarised in Table 11. Temperature is the most comprehensively maintained data base, especially in meteorological journals of the HBC and expeditions. At those locations where data spanned more than a 20-year period, temperature would normally be adequate to

determine seasonal and annual normals. There are also sufficient records to calculate potential evapotranspiration using the methods of Thornthwaite (1948) which utilise only mean temperature. Precipitation data in modern form are rare but there may be enough of them to justify the computation of actual evapotranspiration and soil moisture change on a regional scale (Mather, 1964). Frequency data are numerous. They can be used directly to supplement our sense of the climate as well as for extreme weather analyses.

The quantity and quality of records of wind direction are impressive. When combined with temperature, wind direction should provide a good base for airmass analyses in both time and space. Such analyses would be beneficial in the search for causal linkages in droughts and floods, their time and spatial persistence.

Two recommendations which could enhance the productive utilisation of the diverse data base are:

1. Efforts should be directed towards the calibration of all data held in major historical documents including the translation of non-numerical to numerical data. Such calibration should include a statement on the confidence level associated with the transformation.
2. Spatial maps on major historical climatic events such as droughts should now be attempted based on modern day correlations. This will involve the extrapolation of limited spatial data collected during the early stages of European activities in the Prairies. Such maps could refine the calibration recommended in (1).

7.3.2 *Prehistorical Data.* The time domain, the minimum sampling interval, and the type of climatology that may be inferred from paleoenvironmental data, are listed in table 1 to which reference should now be made. Bogs and lake

Table 11. Types of data contained in historical documents

| *Document* | *Temperature* | *Precipitation* | *Wind* | *Weather* | *Remarks* |
|---|---|---|---|---|---|
| Post Journals (meteorological) | 2 or 3 temp. daily numerical values | Infrequent numerical daily values. Frequency usually reported. Duration rare. | Direction usually given. Wind speed rare unless it is gale force. Qualitative description of average strength and gustiness. | Always reported in terms of sky condition. | |
| Post Journals (non-meteorological) | Daily averages in non-numerical form (cold, warm . . .) except in severe weather when estimates of max and min are reported | Frequency reported numerical estimates in severe weather. | Direction normally given. Usually silent on speed except during severe weather. | Usually reported in subjective terms (fine, pleasant, disagreeable). | Attempts made to provide a comparison between present and normal weather. Seasonal departures often discussed especially when weather is unusual. |
| Explorers' diaries | 2 or 3 temperature reports daily. Many gaps found in diaries except when a technical team is part of expedition and data them is continuous. Non-numerical entries common. | Rare reports on precipitation. Numerical estimates reported for severe weather. | Direction normally reported. Strength data unusual unless wind is gale force. | Usually reported in subjective terms (fine, pleasant, disagreeable . .). | Wide spatial coverage but data is transect except where expedition leave behind instruments and instructions that records be continued. |
| Surveyor's notebooks | Occasional numerically data. Normally once daily. Non-numerical data also occasionally reported. | Usually frequency. Occasional estimates of depth. | Direction occasionally given. Report on strength rare. | Occasional entry. | Meteorological data is spotty in most journals. Seasonal summaries appear from time to time. Soil moisture, floods and droughts are reported normally as part of a seasonal or spatial summary. |

*Table 11 continued*

*Table 11 continued*

| *Document* | *Temperature* | *Precipitation* | *Wind* | *Weather* | *Remarks* |
|---|---|---|---|---|---|
| Settler's chronicles | Daily entries very occasional except during severe weather. Data form is usually non-numerical. | Daily values rarely reported. Frequency not given. | Rare. | Rare. | Good accounts of seasonal weather. Departures from normal and other experiences usual. Excellent evaluation on impact on agriculture and trade. Spatial dimension well represented. |
| North West Mounted Police | Most entries are non-numerical. Occasional numerical data supplied but usually associated with severe weather. Some evidence that an official register was close by. | Daily frequency reported. Few numerical data. | Wind direction normally reported. It is not always clear if data represents a daily average or specific condition. | Usually recorded. | Entries are of uneven quality. The interest of the recording officer appears to indicate what is written. Forest fire data well preserved. |
| The Churches | Entries are rare except in Colleges and some mission schools. Non-numerical data are usual. | Rare. | Rare except during severe weather. | Rare. | |
| Private weather diaries | Twice daily and numerical. Quality uneven. | Daily values given in both frequency and amounts. | Wind direction given. Wind speed is rarely given. | Usually reported. | Private weather diaries are a recent phenomenon. Most do not predate 1900. Several written between 1810 and 1870 found in the records of the Red River Settlement. |
| Newspaper | Summaries of daily mean and maximum temperature. | Summaries of daily values. | Not normally reported except in news stories. | Not part of the summary. News story may contain. | Phenological phenomenon, weather related environmental news supplied. Good seasonal summaries. |

sediments have a minimum sampling interval of 200 years. Layered lake sediments have a finer resolution and may yield annual to decadal data on temperature, precipitation and soil moisture. In the studies examined, it would appear that resolutions less than 200 years should not be expected here in the prairies. Tree rings would normally yield annual averages of temperature, precipitation and soil moisture. If appropriately calibrated, seasonal, and in some cases, shorter time periods in the range of several days are possible.

It is unlikely that prehistoric data yielded by paleobotanical and sediment-based reconstruction will provide monthly and seasonal climatic signals on an annual scale. There is no indication that the science is aspiring towards such goals whose realisation would be dependent on the nature of the target fossil material as well as the dating techniques employed. Dendrochronology, however, is the area where the most strides are being made. It might be possible to recover very accurate seasonal and monthly data on temperature, precipitation, evaporation and soil moisture for this technique. However, because the prairies are tree poor, and because few of the trees there are both sensitive and predate historical records by a substantial margin, it is unlikely that as an independent source for prehistoric data, they will be of much value in the prairies at this time.

## 8. CONCLUSIONS

•Unlike in Europe where several centuries of documented meteorological history exists, written records on climate in the prairies did not begin until the arrival of the first europeans. Because it was the "beachhead" for the penetration of the whiteman into the prairies, Manitoba including the Hudson Bay has the longest record. Here, if the records at the HBC at the Bay and those of other european traders around Lake Superior and in Minnesota are included, at least 300 years of data could be recovered. The data quality for the period 1650-1750 is

uneven though useable. The length of record diminishes irregularly westwards. In Alberta, reliable data did not exist before 1790 and even those were very much restricted to the Athabasca district and the North. Before c. 1840, spatial distribution of "stations" for the prairies as a whole was poor. After 1840, data can be found for most modern towns and cities. My assessment is that practical data useful for mapping climate in the prairies as a whole is about 200 years long, 1790 being the early date. However, another 50 years of data from 1740 to 1790 can be used with reduced confidence.

In sum, it seems feasible to reconstruct climatologies of the prairies for the whole of the 19th century with relative ease. The second half of the 18th century can be recovered but with less precision. The precision can be improved, however, by working backwards, i.e. by assuming that present patterns were exact analogues of the past. Such assumption should allow the researcher to extrapolate the climatic configuration of data poor areas from that obtained from data rich ones.

Before drawing climatic maps based on documented evidence, it is absolutely essential to understand the existing spatial connections and even teleconnections which bind the prairies together climatologically. Should the maps include a significant number of inferred data, it might be useful to assign probabilities to each of them.

A reasonable beginning to mapping early document based prairie climates should involve "severe" weather including spatially persistent events such as droughts and to a lesser degree wet events and storms. This is because records of very severe weather appear in numerical form in both "official" records and in forms that do not always exclude quantitative data, in private diaries. United States data are also available.

Three variables appear to lend themselves to historical mapping namely; temperature, precipitation frequency and wind direction. This is because data are most abundant in both in the temporal and spatial dimensions. It is unlikely that amounts of precipitation and wind speed can be mapped with precision before 1840 because of inadequacy in spatial resolution. The feasibility of deriving both types of data from other information should be explored. Derived data can also be used for mapping evapotranspiration, soil moisture and the water balance.

It is not necessary to cover all provinces simultaneously as a unit. Indeed, a proxy document based mapping of climate could begin with Manitoba where data is most numerous and extend subsequently to Alberta. Following this, spatial integration should be attempted beginning with periods for which records are available for all areas and progressing through to those periods in which large gaps exist.

It is advantageous to select the "period" mapped very carefully. The pursuit of "normals" may require that climatic maps be produced for say 1700 to 1750. However, such maps may not turn out to be as useful as those based on periods of aberrations – droughts, warmer temperatures, wet decades . . .. Maps based on deviant series may be extremely useful to our understanding of the nature and impact of those climates whose features coincide with estimates of greenhouse warming based on General Circulation models. Such maps will also be of value to students of the environment, archeology, anthropology and history.

•Proxy data from tree rings exist but are not numerous. Annual and seasonal data on temperature and precipitation can be obtained. Few tree ring data series predate documented data. However, what data are available are good especially for the 150 Years Before Present. They should be used to supplement and in some cases calibrate some of the maps drawn from documented records. Fortuitously, Alberta which has the least number of documented records has

some of the more impressive sets of dendroclimatological data for the period in which documents are lacking. Tree ring data will also be invaluable for calibrating soil moisture conditions *derived* from documented information if a decision is made to map that variable.

•Paleobotanical data are most abundant for Middle and Late Holocene. Time lines are too coarse to enable determination of annual and seasonal temperature series equivalent to what might be obtained form either documented records or tree rings. Data is most numerous for Alberta and least for Saskatchewan. It is unlikely that the data obtained from this source would have a precision comparable to documented and tree ring data for contemporary mapping. However, the evidence revealed could also be used to calibrate the edges of maps drawn from other proxy sources.

## REFERENCES


Ali, M.F. and J.A. Mawdsley, 1987: Comparison of two recent models for estimating actual evapotranspiration using only regularly recorded data. *Journal of Hydrology, 93,* 257-276.

Allsopp, T.R., 1977: *Agricultural weather in Red River basin of southern Manitoba over the period 1800 to 1975.* Fisheries and Environment Canada, AES CL1-3-77, 28 pp.

Anderson, J.W., 1961: Fur Trader's Story. Toronto. Manitoba Provincial Archives, Winnipeg.

Anderson, T.W., R.W. Mathewes and C.E. Schweger, 1989: Holocene climatic trends in Canada with special reference to the Hypsithermal interval. *In* R.J. Fulton (ed.), Chapter 7 of *Quaternary Geology of Canada and Greenland,* Geological Survey of Canada.

Antevs, E., 1955: Geologic climatic dating in the West. *American Antiquity,* 317-335.

Ashworth, C.A. and A.M. Cvancara, 1983: Paleoecology of the southern part of the Lake Agassiz Basin. *In* T.J. Teller and L. Clayton (eds.), *Glacial Lake Agassiz,* Geological Association of Canada, Special Paper 26, 133-156.

Aughey, S., 1880: *Sketches of the Physical Geography and Geology of Nebraska.* Omaha, Nebraska: Daily Republican Book and Job Office, 326 pp.

Baird, A.B., 1886: *North West Territories – travel and description: some old time stories of winter travel in the West.* Manuscript Group 9 A2-2, A2-3 and A2-4. Manitoba Provincial Archives, Winnipeg.

Ball, T.F., 1983: The migration of geese as an indicator of climate change in the southern Hudson Bay region between 1715 and 1815. *Climatic Change,* 5, 83-93.

Banfield, A.W.F., 1958: The mammals of Banff National Park, Alberta. National Museum of Canada, Ottawa Bulletin 159.

Barnes, P.W., L.L. Tieszen and D.J. Ode, 1983: Distribution, production and diversity of $C_3$ and $C_4$ dominated communities in a mixed prairie. *Canadian Journal of Botany, 61,* 741-751.

Baron, W.R., 1982: The reconstruction of 18th century temperature records through the use of content analysis. *Climatic Change,* 4, 385-398.

Bell, C.N., 1898: Alexander Henry's journal covering adventures and experiences in the fur trade on the Red River 1799-1801. Paper read before the Historical and Scientific Society of Manitoba, May 4, 1898. Available in microfische.

Bernabo, J.C. and T. Webb III, 1977: Changing patterns in the Holocene pollen record of northeastern North America: a mapped summary. *Quaternary Research, 8*, 64-96.

Blakiston, T., 1858: Letters from T. Blakiston to Capt. John Palliser. *In Further Papers Relative to the Explorations by Captain Palliser of that Portion of British North America which Lies Between Branch of the River Saskatchewan and the Frontier of the United States and Between the Red River and the Rocky Mountains*, Greinwood Press, New York, 1859.

Blodgett, L., 1857: *Climatology of the United States*, Philadelphia.

Borchert, J.R., 1971: The dust bowl in the 1970s. *Annals*, Association of American Geographers, *61*, 1-22.

Brooks, C.E.P., 1954: The climatic changes of the past thousand years. *Experientia* (Basle), vol. x(4), 153-158.

Brougham, F., 1966: Paleoenvironments of the eastend, Whitemud formation, eastern Cypress Hills, Saskatchewan. Unpubl. M.Sc. thesis, University of Saskatchewan, Saskatoon.

Bryson, R.A., D.A. Baerreis and W.M. Wendland, 1970: The character of late glacial and post glacial climatic changes. *In* W. Dort. Jr and J.K. Jones (eds.), *Pleistocene and Recent Environments of the Central Great Plains*, University Press, Lawrence, Kansas.

Bryson, R.A. and T.J. Murray, 1977: *Climate and Hunger*, University of Wisconsin Press.

Carrera, P.E., S.K. Hort, and R.E. Wilcox, 1976: Deglaciation of mountainous regions of northwestern Montana, as indicated by late pleistocene ashes. *Arctic and Alpine Res., 18*, 317-325.

Catchpole, A.J.W., 1980: Historical evidence of climatic change in western and northern Canada. *In* C.R. Harington (ed.), *Syllogeus*, 26, National Museum of Canada, Ottawa, 17-60.

Catchpole, A.J.W. and T.F. Ball, 1981: Analysis of historical evidence of climate change in western and northern Canada. *In* C.R. Harington (ed.), *Syllogeus*, 26, National Museum of Canada, Ottawa, 47-96.

Catchpole, A.J.W., D.W. Moodie and B. Kaye, 1970: Content analysis: a method for the identification of first freezing and first breaking from descriptive accounts. *Professional Geographer, 22*, 252-257.

Catchpole, A.J.W., D.W. Moodie and D. Milton, 1976: Freeze-up and break-up of estuaries on Hudson Bay in the eighteenth and nineteenth centuries. *Canadian Geographer, 20*, 279-297.

Champlain Society, 1988: *The Journal of Alexander Henry the Younger*, 1799-1814. (Gough, B.M., ed.), Toronto.

Chisolm, B.S., J. Driver, S. Dube, and H.P. Schwarez, 1986: Assessment of prehistoric bison foraging and movement patterns via stable-carbon isotope analysis. *Plains Anthropologist, 31*, 193-205.

Christiansen, E.A., 1979: The Wisconsonian deglaciation of southern Saskatchewan and adjacent areas. *Canadian Journal of Earth Sciences, 16*, 913-938.

Christiansen, E.A., 1982: Saskatchewan River Delta of Lake Agassiz near Nipawin, Saskatchewan. Geological Association of Canada, programs with abstract 1, p. 43.

Cook, R.E., 1986: Statistical methods on the disaggregation of tree ring series for environmental studies. *In* G.C. Jacoby and J.W. Hornbeck (eds.), *Proceedings*, International Symposium on Ecological Aspects of Tree-ring Analysis, August 1986, Terrytown, U.S. Department of Commerce.

Coupland, R.T., 1958: The effects of fluctuation in weather upon the grasslands of the Great Plains. *Botanical Review, 24*, 274-317.

Dang, Q.L. and V.J. Leiffer, 1989: Climate and annual ring growth of black spruce in some Alberta peatland. *Canadian Journal of Botany, 67*, 1885-1889.

D'Arrigo and G. C. Jacoby, 1990: Northern North America: temperature trends in tree growth. *In* R.S. Bradley and P.D. Jones (eds.), *Climate Since A.D. 1500*, Unwin Hyman Co.

David, P.P., 1981: Stabilised dune ridges in northern Saskatchewan. *Canadian Journal of Earth Sciences, 18*, 286-310.

Davis, M.B., 1984. Climatic instability, time lags and community ecology. *In* J. Diamond and T.J. Case (eds.), *Community Ecology*, Harper and Row, New York, 269-284.

Davis, O.K., 1984: Multiple thermal maxima during the Holocene. *Science, 225*(4662), 617-619.

Dawson, S.J., 1858: Report on the exploration of the country between Lake Superior and the Red River Settlement. John Lovell, Toronto.

Dawson, G.M. 1879: Peace River Geological and Natural History. Survey of Canada, Report of Progress, Montreal 1879-80, 468-798.

Dean, W.E., J.P. Bradbury, R.Y. Anderson and C.W. Barosky, 1984: The variability of Holocene climate change: evidence from varied lake sediments. *Science, 226* (4679), 1191-1194.

Delorme, L.D., 1966: Pleistocene and post-pleistocene ostracodes of Saskatchewan. Unpubl. Ph.D. thesis, University of Saskatchewan, Saskatoon.

Delorme, L.D., 1986: Paleoclimatic interpretations from lake sediments. $CO_2$-climate Report, Environmental Canada, Issue 86-2, p. 3.

Dredge, L.A. and W.R. Cowan, 1989: Quaternary geology of the southwestern shield. *In* R.J. Fulton, H.A. Heginbottom, and S. Funder (eds.) Quaternary Geology of Canada and Greenland. *Geological Survey of Canada, No. 1.*

Dredge, L.A. and E. Nielsen, 1985: Glacial and interglacial deposits in the Hudson Bay Lowland: a summary of sites in Manitoba. *In Current Research, Part A.*, Geological Survey Paper 85-1A, 247-257.

Dredge, L.A. and E. Nielsen, 1987: Glacial and interglacial stratigraphy, Hudson Bay Lowlands, Manitoba. Geological Society of American Field Guide, North-Central Section, 43-46.

Eleringer, J.R., 1978: Implications of quantum yield differences on the distributions of $C_3$ and $C_4$ grasses. *Oecologia, 31*, 255-267.

Elias, S.A., 1988. Climatic significance of late pleistocene insect fossils from Marias Pass, Montana. *Canadian Journal of Earth Sciences, 25*, 922-926.

Environment Canada, 1986. Past climates. *$CO_2$ Climate Report, 86-2*, 1-2.

Epp, H.T., 1982: Prehistoric man in the environment at Saskatoon. *In* V. Linuame and E.H. Jones (eds.), *Out of the Past, Sites, Digs and Artifacts in the Saskatoon Area*, Saskatoon Archaeological Society, 39-46.

Faegri, K, 1975: *Textbook of Pollen Analysis.* Third Ed. Hafner, New York, 295 pp.

Forsman, M., 1987: The prehistory of Montreal Lake, Central Saskatchewan. Unpubl. M.Sc. thesis, University of Saskatchewan, Saskatoon.

Fremont, J.C., 1848: *The Expedition of John Charles Fremont: United States Exploring Expedition – West U.S. Description and Travel to 1848. In* D. Jackson, ed.)., University of Illinois Press, Urbana.

Fritts, H.C., 1976: *Tree Rings and Climate.* Academic Press, New York, 567 pp.

Fritts, H.C., T.J. Blasing, B.P. Hayden and J.E. Kutzbach, 1971: Multivariate techniques for specifying tree growth and climate relationships and for reconstructuring anomalies in paleoclimatic. *Journal of Applied Meteorology, 10*, 845-864.

Froese, E., 1956: Metamorphosed sediments of middle Foster Lake area, northern Saskatchewan. Unpubl. M.Sc. thesis, University of Saskatchewan, Saskatoon.

Gladman, G., 1858: *Report on the Exploration of the Country Between Lake Superior and the Red River Settlement.* John Lovell, Toronto.

Grayson, D.K., 1975: *A bibliography of the literature on North American climates of the past 13,000 years.* Garland Publishers, New York, 203 pp.

Glover, R. (ed.), 1962: *David Thompson's narratives.* Champlain Society, Toronto.

Grove, A.T., F.A. Street and A.S. Gordie, 1975: Former lake levels and climatic change in the rift valley of southern Ethiopia. *The Geographical Journal, 141,* 177-202.

Halfpenny, F.G. (ed.), 1966: *Dictionary of Canadian Biography,* vol. XI, 1881 to 1890. University of Toronto Press.

Hansen, H.P., 1949: Post glacial forests in south central Alberta, Canada. *American Journal of Botany, 36,* 54-65.

Hansen, H.P., 1952: Post glacial forests in the Grande Prairie, Lesser Slave Lake region of Alberta, Canada. *Ecology, 33,* 31-40.

Hare, F.K., 1973: On the climatology of post-Winconsinian events in Canada. *Arctic and Alpine Research, 5,* 169-170.

Hare, F.K., 1976: Late Pleistocene and Holocene climate: some persistent problems. *Quaternary Research, 6,* 507-517.

Harris, S.A., 1985: Evidence for the nature of early Holocene climate and paleogeography. *Arctic and Alpine Research, 17,* 49-67.

Heusser, C.J., 1966: Polar Hemispheric Correlation: palynological evidence from Chile and the Pacific Northwest of America. *In* J.S. Sawyer (ed.), *World Climate, from 8000 to 0 B.C.,* Royal Meteorological Society, London, 124-141.

Hickman, M., 1987: The paleoclimatology of a large shallow lake. *Archiv fur Hydrobiologie, III,* 121-136.

Hickman, M., C.E. Schweger and T. Hagwood, 1984: Lake Wabamun, Alberta: a paleoenvironmental study. *Canadian Journal of Botany, 62,* 1438-1465.

Hills, L.V. and E.V. Sangster, 1980: A review of paleobotanical studies dealing with the last 20,000 years; Alaska, Canada and Greenland. *In* C.R. Harington (ed.), *Climate Change in Canada: Syllogeus,* No. 26, National Museum of Natural Sciences, National Museums of Canada, 73-224.

Hoeller, A.E., 1982: The Role of Environmental and Historical Evidence in Climate Reconstruction: a preliminary review and appraisal. Unpubl. Report, Canadian Climate Centre, Report No. 82-3, 113 pp.

Hopkins, D.M. 1972: The paleography and climatic history of Beringia during late Cenozoic time, *Inter-Nord, 12*, 121-150.

Horrel, J., 1946: Weather diary a homesteader in North Battleford, Saskatchewan, 1907-1946. Deposited in the Saskatchewan Provincial Archives, University of Saskatchewan, Saskatoon.

Hudson Bay Company, 1800: Letter from governor and Committee of the Hudson Bay Company to John Thomas and Council, Moose Factory, 28 May 1800. Hudson Bay Company Archives, A6/16 folio 97d.

Idso, S.B., 1988: Greenhouse warming or Little Ice Age demise: a critical problem for climatology. *Theoretical and Applied Climatology, 193*, 54-56.

Jackson, D. (ed.), 1966: *The Journals of Zebulon Montgomery Pike with letters and related documents* (2 volumes)., University of Oklahoma Press.

Jacoby, G. and E.R. Cook, 1981: Past temperature variations inferred from a 400-year tree ring: a chronology from Yukon Territory, Canada. *Arctic and Alpine Research, 15*, 409-418.

Jones, D.C., 1987: *Empire of Dust*. The University of Alberta Press, Edmonton, 316 pp.

Jozsa, L.A., S.G. Johnson and P.A. Bramhall, 1984a: X-ray densitometric analysis of an old Douglas-fir stand from Banff, Alberta. Report to the University of Alberta, Edmonton by Forintek Canada Corporation, 02-80-82-604.

Jozsa, L.A., M.L. Parker, P.A. Bramhall and S.G. Johnson, 1984b: *How climate affects tree growth in the Boreal forest*. Canadian Forestry Service, Northern Forest Research Centre, Inf. Report NOR-X-255.

Jungerius, P.D., 1969: Soil evidence of post glacial tree line fluctuations in the Cypress Hills area, Alberta Canada. *Arctic and Alpine Research, 1*, 235-246.

Kearney, M.S. and B.H. Luckman, 1979: Evidence for late Wisconsin-early Holocene climatic/vegetational change in Jasper National Park, Alberta. *In* W.C. Maheney (ed.), *Quaternary Paleoclimate*, York University, Geo. Abstracts Ltd., University of East Anglia, 85-105.

Kearney, M.S. and B.H. Luckman, 1983: Holocene vegetational and climatic history of Tonquin Pass, B.C.. *Canadian Journal of Earth Sciences, 20*, 776-786.

King, J.E., 1981: Late Quaternary vegetational history of Illinois. *Ecological Monographs, 51*, 43-62.

Kunkel, K.D. and J.R. Angel, 1988: Perspective on the 1988 midwestern drought. *EOS Transactions, American Geophysical Union, 70*(36), p. 817.

Kutzbach, J.E., 1975: Diagnostic studies of past climates. *In The physical Basis of Climate Modelling*. GARP Publication Series No. 16, WMO, Geneva, Switzerland, 119-126.

Kutzbach, J.E. and P.J. Guetter, 1986: The influence of changing orbital parameters and surface boundary conditions on climate simulations for the past 18000 years. *Journal of the Atmospheric Sciences, 43*, 1726-1759.

Lamb, H.H., 1966: *The Changing Climate*. Methuen, London.

Lamb, H.H., 1977: *Climate: Present, Past and Future*. Methuen, London, vol. 2, climatic history and the future, 835 pp.

Lamb, H.H. and H.T. Morth, 1978: Arctic ice, atmospheric circulation and world climate. *Geographical Journal, 144*, 1-22.

Landsberg, H.E., 1976: The definitions and determinations of climatic change fluctuations and outlooks. *In* R.J. Kopec (ed.), *Atmospheric Quality and Climatic Change*, Studies in Geography No. 9, University of North Carolina at Chapel Hill, 46-52.

Lawrence, E.N., 1972: The earliest known journal of the weather. *Weather, 27*, 494-501.

Laycock, A.H., 1973: Lake level fluctuations and climatic variations in central Alberta. *In* E.R. Reinelt, A.H. Laycock and W.M. Schultz (eds.), *Proceedings of the Symposium on the Lakes of Western Canada*, University of Alberta, Water Resources Centre, Edmonton, Pub. 2, 83-96.

Linuame, V. and T.E.H. Jones (eds.), 1982: *Out of the Past, Sites, Digs and Artifacts in the Saskatoon area*. Saskatoon Archaeological Society.

Lichti-Federovich, J., 1970: The pollen stratigraphy of a dated section of late Pleistocene lake sediments from Central Alberta. *Canadian Journal of Earth Sciences, 7*, 938-945.

Lichti-Federovich, J. and J.C. Ritchie, 1968: Recent pollen assemblages from western interior of Canada. *Review of paleobotany and palynology, 7*, 297-344.

Looman, J., 1983: Distribution of plant species and vegetation types in relation to climate. *Vegetatio, 54*, 17-25.

Lowe, A.B., 1961: Canada's first weathermen. *The Beaver*, Summer 1961, 4-7.

Mackay, G.A., 1978: Mitigation of the effects of drought with special reference to the Canadian experience. *In* N. Rosenberg (ed.), *Droughts in the Great Plains*, Water Resources Publication, Littleton, Colorado, 168-180.

MaCoun, J., 1882: *Manitoba and the Great Northwest*. Guelph, Ontario.

MacDonald, G.M., 1982: Quaternary paleoenvironments of Morley Flats and Kananaskis Valley of southwestern Alberta. *Canadian Journal of Earth Sciences, 19*, 23-35.

MacDonald, G.M. and J.C. Ritchie, 1986: Modern pollen spectra from western interior and the interpretation of late quaternary vegetational development. *New Phytologist, 103*, 245-268.

Malin, J.C., 1944: ***Winter Wheat in the Golden Belt of Kansas***, University of Kansas Press, Lawrence, 290 pp.

McKinnon, N.A., 1987: Paleoenvironments and cultural dynamics at Head-Smashed-In-Buffalo-Jump, Alberta. National Library of Canada, Ottawa.

Marten, H., 1760: Severn House Journal. Record of the Activities of the Hudson Bay Company at the Severn House Post. Hudson Bay Company Archives, Winnipeg, Manitoba.

Mather, J.R. (ed.), 1964: Average climatic water balance data of the Continents Publications. *In* Climatology, vol. 17, C.W. Thornthwaite Associates, North America, Centerton, New Jersey, 414 pp.

Mayer-Oakes, W. (ed.), 1966a: ***Life, Land and Water***. University of Manitoba Press, Winnipeg.

Mayer-Oakes, W., 1966b: Prehistoric human population history of the Lake Agassiz region. *In* W. Mayer-Oakes (ed.), ***Life, Land and Water***, University of Manitoba Press, Winnipeg, 339-414.

McHugh, T., 1958: Social behaviour of the American buffalo. *Zoologia, 43*, 1-46.

Meko, D.M., C.W. Stockton and W.R. Boggess, 1980: A tree-ring reconstruction of drought in southern California. *Water Resources Bulletin, 16*, 594-600.

Miuni, S., 1969: The prehistoric occupation of Black Lake, Northern Saskatchewan. Unpubl. M.Sc. thesis, University of Saskatchewan, Saskatoon.

Moodie, D.W., 1977: The Hudson Bay Company Archives: a resource for historical geography. *The Canadian Geographer, 21*, 268-274.

Moss, E.H., 1955: The vegetation of Alberta. *The Botanical Review, 21*, 493-567.

Mott, R.J., 1973: Palynological studies in central Saskatchewan, pollen stratigraphy from lake sediment sequences. Geological Survey of Canada Papers 72-49, 18 pp.

Mott, R.J. and L.E. Jackson, Jr., 1982: An 18000 year palynological record from the southern Alberta segment of the classical Winconsonian "ice free corridor". *Canadian Journal of Earth Sciences, 19*, 504-513.

Nambudiri, E.M.W. and C.T. Shay, 1986: Late Pleistocene and Holocene pollen stratigraphy of the Lake Manitoba basin, Canada. *Palaeontrographica* Abteilung *B, 202,* 155-177.

*National Atlas of Canada,* 1987: Canada Centre for Mapping, Energy, Mines and Resources, Ottawa.

Nielsen, E. and L. Dredge, 1982: Quaternary stratigraphy and geomorphology of a part of the Lower Nelson River. Geological Association of Canada, Field Trip S, Guidebook, 56 pp.

Nielsen, E., C.S. Churcher and G.E. Lammers, 1988: A woolly mammoth from the Hudson Bay lowlands of Manitoba. *Canadian Journal of Earth Sciences, 25,* 933-938.

Nielsen, E., D.H. McNeil and W.B. McKillop, 1987: Origin and paleoecology of past-Lake Agassiz raised beaches in Manitoba. *Canadian Journal of Earth Sciences, 24,* 1478-1485.

Nkemdirim, L.C., 1988: On the frequency of precipitation day in Calgary, Canada. *Professional Geographer, 40,* 65-77.

Nkemdirim, L.C. and D. Venkatesan, 1985: An urban impact model for changes in the length of the frost free season at selected Canadian stations. *Climatic Change 7,* 343-362.

Palliser, J., 1859. Report from Captain John Pallisers to Her Majesty's Secretary for the colonies. In *Papers Related to the Exploration by Captain John Palliser of that Portion of British North American Which Lies Between the Northern Branch of the River Saskatchewan and the Frontiers of the U.S. and Between the Red River and the Rocky Mountains.* Greenwood Press, New York.

Palliser, J., 1860. Further Papers Relative to the Exploration by the Expedition Under Captain Palliser. Her Majesty's Stationery, London.

Parker, M.L. and Henoch, W., 1971: The use of Englemann Spruce late-wood density for dendrochronological purposes. *Canadian Journal of Forest Resources, 1,* 90-98.

Parker, M.L., W.E. Henoch and P.A. Bramhall, 1977: Tree-ring width and density related to climatic factors in the Yukon Territory. Canadian Forestry Service, Western Forest File Report.

Pettipas, L., 1975: Prehistoric drought and population redistribution on the Northern Plains. *Saskatchewan Archaeology Newsletter, 51,* 1-12.

Pettipas, L., 1976: Environmental change and cultural dynamics during the paleo-Indian Period. With special reference to Manitoba. *Department of Tourism,*

*Recreation and Cultural Affairs, Historic Resources Branch, Papers in Manitoba Archaeology, Miscellaneous Papers No. 1*, 19-40.

Pettipas, L., 1981: Vegetational and pedological change in the Parkland Belt and their implications for Archaeology. *Manitoba Archaeological Quarterly, 5*, 25-36.

Pettipas, L. and A.P. Buchner, 1983: Paleo-Indian Prehistory of the Glacial Lake Agassiz Region in Manitoba, 11500 to 6500 B.P. *In* J.T. Teller and L. Clayton (eds.), *Glacial Lake Agassiz*, Geological Association of Canada Special Paper *26*, Toronto.

Pielou, E.C., 1979: *Biogeography*. John Wiley, New York, 351 pp.

Pike, Z.M., 1810: *In* D. Jackson (ed.), *Journals of Zebulon Montegomery Pike with letters and related documents (2 volumes)*, University of Oklahoma Press, 1966.

Prentice, N., 1983: The Tschelter site: a study of a late prehistoric bison kill. Unpubl. M.A. thesis, University of Saskatchewan, Saskatoon.

Rannie, W.F., 1983: Break-up and freeze-up of the Red River at Winnipeg, Manitoba, Canada, in the 19th century and some climatic implications. *Climatic Change*, 5, 283-296.

Rannie, W.F. L.H. Thorleifson an J.T. Teller, 1989: Holocene evolution of the Assiniboine River paleochannels and Portage la Prairie alluvial fan. *Canadian Journal of Earth Sciences, 26*, 1834-1841.

Readman, B.B., 1964: *Days That Are Gone*. Personal Memoirs, Manitoba Provincial Archives, Winnipeg, Manitoba.

Reider, R.G., G.A. Huckleberry and G.C. Frison, 1988: Soil evidence for post glacial forest-grassland fluctuations in the Absaroka Mounts of Northwestern Wyoming, U.S.A. *Arctic and Alpine Research, 20*, 188-198.

Reeves, B.O.K., 1973: The concept of an alithermal cultural hiatus in Northern plains prehistory. *American Anthropologist, 75*, 1121-125.3

Ritchie, J.C., 1964: Contributions to the Holocene paleoecology of west central Canada 1. Riding Mountain area. *Canadian Journal of Botany, 43*, 181-197.

Ritchie, J.C., 1967: Holocene vegetation of the northwestern precincts of the Glacial Lake Agassiz basin. *In* W.J. Mayer-Oakes (ed.), *Life, Land and Water*, University of Manitoba Press, Winnipeg, Manitoba, 217-229.

Ritchie, J.C., 1972: Pollen analysis of late Quaternary sediments from the Arctic treeline of the Mackenzie River Delta Region, Northwest Territories, Canada *In Climatic changes in Arctic Areas During the Last Ten Thousand Years*. Acta

Universitatis Oulensis, Series A., Scientiae Rerum Naturalium No. 3, Geologica No. 1, University of Oulu, Finland, 253-271.

Ritchie, J.C., 1976: The late-quaternary vegetational history of the western interior of Canada. *Canadian Journal of Botany, 54*, 1793-1818.

Ritchie, J.C., 1983a: Reconstructed May-August mean temperature for the Riding Mountain site. Geological Association of Canada Special Paper 26.

Ritchie, J.C., 1983b: The paleoecology of central and northern parts of the Glacial Lake Agassiz basin in Glacial Lake Agassiz (J.T. Teller and L. Clayton, eds.), Geological Association of Canadian Special Papers 26.

Ritchie, J.C., 1984: A Holocene pollen record of boreal forest history from the Travailant Lake area, Lower Mackenzie River basin. *Canadian Journal of Botany, 62*, 1385-1392.

Ritchie, J.C., 1986: Holocene climates of Canada from fossil pollen. *$Co_2$ Climate Report*, Issue 86-2, p. 4.

Ritchie, J.C. 1989: History of the Boreal Forest in Canada. *In* R.J. Fulton (ed.), *Quaternary Geology of Canada and Greenland*, Geological Survey of Canada, Geology of Canada, No. 1, 508-519.

Ritchie, J.C. and B. de Vries, 1964: Contributions to the Holocene paleoecology of west central Canada - a late glacial deposit from the Missouri Coteau. *Canadian Journal of Botany, 42*, 677-692.

Ritchie, J.C. and K. Gajewski, 1986: Holocene climates of Canada from fossil pollen. $CO_2$ Climate Report, Issue 86-2, p. 4.

Ritchie, J.C. and F.K. Hare, 1971: Late Quaternary vegetation and climate near the Arctic tree line of northwestern North America. *Quaternary Research, 1*, 331-342.

Ritchie, J.C. and S. Lichti-Federovich, 1968: Holocene pollen assemblages from the Tiger Hills, Manitoba. *Canadian Journal of Earth Sciences, 5*, 873-1588.

Robertson, E.O. and L.A. Jozsa, 1988: Climatic reconstruction from tree rings at Banff. *Canadian Journal of Forestry Resources, 18*, 888-900.

Ross, J., 1853: Personal papers of the Rev. James Ross of the Church of England. The Ross Collections, Public Archives of Manitoba, folio 49.

Schweger, C.E., 1984: A critical appraisal of the Altithermal and its role in archaeology. *In* N.A. McKinnon and G. Stuart (eds.), Man and the Mid-Holocene Climatic Optimum, University of Calgary Archaeological Society.

Schweger, C.E., T. Habgood and M. Hickman, 1981: Late Glacial-Holocene climatic change of Alberta. The record from lake sediment. In *The Impacts of*

*Climatic Fluctuations on Alberta Resources and Environment.* Environment Canada, Report WAES-1-81, 47-59.

Schweger, C.E. and M. Hickman, 1989: Holocene paleohydrology of Central Alberta; testing general circulation-model climate simulations. *Canadian Journal of Earth Sciences, 26,* 1826-1833.

Schweger, C.E. and M. Hickman, 1980: Post glacial palynology and limnology, Alberta, Western Canada. Abstract to International Palynological Conference, Cambridge, U.K., p. 357.

Scott, P.A., D.C.F. Fayle, C.V. Bentley, and R.I.C. Hansel, 1988: Large-scale changes in atmospheric circulation interpreted from patterns of tree growth at Churchill, Manitoba, Canada. *Arctic and Alpine Research, 26,* 199-211.

Smit, I. and L.C. Nkemdirim, 1990: The climate of Southern Alberta in the nineteen-eighties viewed from a historical perspectives. University of Calgary Climate Centre Publication 90-1, 50 pp.

Sheppe, W. (ed.), 1962: *First Man West: Alexander Mackenzie's Account of His Expedition Across North America to the Pacific in 1973.* McGill University Press.

Sorenson, C.J., J.C. Knox, J.A. Larsen and R.A. Bryson, 1971: Paleosoil and the forest border in Keewatin, N.W.T. *Quaternary Research, 1,* 468-473.

Spry, I., (ed.), 1968: The papers of the Palliser Expedition 1857-1860. Publication No.44, Champlain Society, Toronto.

Stalker, A.M. and R.J. Mott, 1972: Palynology of the "Kansan" carbonaceous clay unit near Medicine Hat, Alberta. *In* Report of Activities, Part B., Geological Survey of Canada Paper 72-1B, 117-119.

Staton, F.M., 1931: *The Canadian Northwest.* A bibliography of sources of information in the public library of the City of Toronto in regard to the Hudson's Bay Company, the fur trade and the early history of the Canadian North-west. Toronto Public Library, Toronto, Ontario.

Stockton, C.W., 1977: Interpretation of past climatic variability from paleoenvironmental indicators. In *Climate, Climatic Change and Water Supply.* National Research Council, National Academy of Sciences, Washington, D.C., 34-45.

Stockton, C.W. and H.C. Fritts, 1971: The feasibility of augmenting hydrologic records using tree-ring data. *First Annual Proceedings of the Arizona Chapter of the American Water Resources Research Association,* April 22-23, Tempe, Arizona, 1-12.

Stockton, C.W. and H.C. Fritts, 1973: Long-term reconstruction of water level changes for Lake Athabasca by analysis of tree rings. *Water Resources Bulletin, 9*, 1006-1027.

Stockton, C.W. and D.M. Meko, 1975: A long-term history of drought occurrence in Western United States as inferred from tree rings. *Weatherwise, 28*, 244-249.

Street, F.A. and A.T. Groves, 1979: Global maps of lake level fluctuations since 30000 B.P. *Quaternary Research, 12*, 83-118.

Sutherland, A.H., 1938: *The Selkirk Settlement on the Red Deer*. Peel Bibliography Series.

Teller, J.T. and L. Clayton (eds.), 1983: Glacial Lake Agassiz. Geological Association of Canada Special Paper 26, Toronto.

Teller, J.T. and W.M. Last, 1979: Post glacial sedimentation and history in Lake Manitoba. Manitoba Department of Mines, Natural Resources and Environment Report 79-41.

Teller, J.T. and W.M. Last, 1981: Late Quaternary history of Lake Manitoba, Canada. *Quaternary Research, 16*, 97-116.

Teller, J.T. and W.M. Last, 1982: Pedogenic horizons in lake sediments. *Earth Surface and Landform, 1*, 367-379.

Thomas, K., 1965. Climatic trends on the Canadian prairies. In *Water and Climate*. Water Studies Institute Report No. 2, Saskatoon, 21-25.

Thornthwaite, C.W., 1948: An approach towards a national classification of climate. *Geographical Review, 38*, 55-94.

Trueman, H., 1887: Letter written to the *St. John Sun and Sackville Post* by Howard Trueman on his journey from Winnipeg to Brandon, Manitoba, September 1887.

Tyrell, J.B., 1916: Narrative of David Thompson's Exploration in North America 1784-1812. Publication of the Champlain Society, Toronto, Vol. XII.

Vance, R.E., 1986: Aspect of post glacial climate of Alberta: calibration of the pollen record. *Géographie physique et Quaternaire, 40*, 153-160.

Vance, R.E., 1987: Meteorological records of prehistoric droughts as climate analogues for the Holocene. *In* N.A. McKinnon and G.S.L. Stuart (eds.), *Man and the Mid-Holocene Climatic Optimum*, The University of Calgary Archaeological Association, Calgary, Alberta, 17-32.

Vance, R.E., D. Emerson and T. Habgood, 1983: A mid-Holocene record of vegetative change in central Alberta. *Canadian Journal of Earth Sciences, 20,* 364-376.

Wallace, W.S., 1934: *Documents relating to the Northwest Company.* Champlain Society, Toronto.

Wallen, C.C., 1963: *Changes of Climate.* Proceedings of the Rome Symposium organised by Unesco and the World Meteorological Organisation. UNESCO, Paris, 467-473.

Ware, H., 1841: *Hunting Tour of the Western Prairies.* National Archives of Canada, Ottawa.

Weakly, H.E., 1965: Prehistoric droughts from tree rings. *Agricultural Engineering, 46,* 85-96.

Webb, W.P., 1931: *The Great Plains.* Grosset and Dunlap, New York, 525 pp.

Webb, T., III, 1986: Is vegetation in equilibrium with climate? How to interpret late quaternary pollen data. *Vegetatio, 67,* 75-91.

Webb, T., III, F.A. Street-Perrott and J.E. Kutzbach, 1987: Late-Quaternary paleoclimatic data and climate models. *Episodes, 10,* 4-6.

Wells, P.V., 1970: Vegetational history of the Great Plains: a post glacial record of coniferous woodland in southeastern Wyoming. *In* (W. Dort and J.K. Jones (eds.), *Pleistocene and Recent Environments of the Central Great Plains,* University of Kansas Press, Lawrence, Kansas.

White, J.M. and R.W. Mathewes, 1982: Holocene vegetation and climatic changes in the Peace River district, Canada. *Canadian Journal of Earth Sciences, 19,* 55-576.

White, J.M. and R.W. Mathewes, 1986: Post glacial vegetation and climatic change in the upper Peace River district, Alberta. *Canadian Journal of Botany, 64,* 2305-2318.

Whittaker, R.M., 1975: *Communities and Ecosystems* (2nd Edition), Macmillian, New York, 385 pp.

Wilson, C.V., 1982: *The summer season along the east coast of Hudson Bay during the nineteenth century, Part I: General Introduction: Climatic Controls; calibration of instrumental temperature data, 1814 to 1821.* Unpubl. Report No. 82-4, Canadian Climate Centre, Atmospheric Environment Service, Toronto, 223 pp.

Wilson, C.V., 1983: *The Summer Season along the east coast of Hudson Bay during the 19th century, Part II: The Little Ice Age on eastern Hudson Bay:*

*Summers at Great Whale, Fort George, Eastmain, 1814 to 1821*. Unpubl. Manuscript Environment Canada, AES CCC Report 83-9, 145 pp.

Wilson, C.V., 1985: The summer season along the east coast of Hudson Bay during the nineteenth century, part III: Summer thermal wetness indices. A Methodology, Unpubl. Manuscript, Canadian Climate Centres, Downsview. Report no. 85-3.

Wilson, M.A., 1981: The climatic and vegetational history of the post glacial in central Saskatchewan. Unpubl. Ph.D. thesis, University of Saskatchewan, Saskatoon, 189 pp.

Wilson, M.A., 1982: A palynological study of core samples from the beds of three ponds in the Nipawin Heritage study area. *In* D. Burley and D. Meyer (eds.), *Nipawin Reservoir Heritage Study*, vol. 3, SRC publications No. C-805-25-E-82, 290-318.

Wilson, M.C. and L.V. Hills, 1984: Holocene white tailed deer from the foothills northwest of Calgary, Alberta. *Canadian Journal of Earth Sciences, 21*, 365-371.

Wijmstra, T.A., 1978: Paleobotany and climatic change. *In* J. Gribbin (eds.), *Climatic Change*, Cambridge University Press, New York, 25-45.

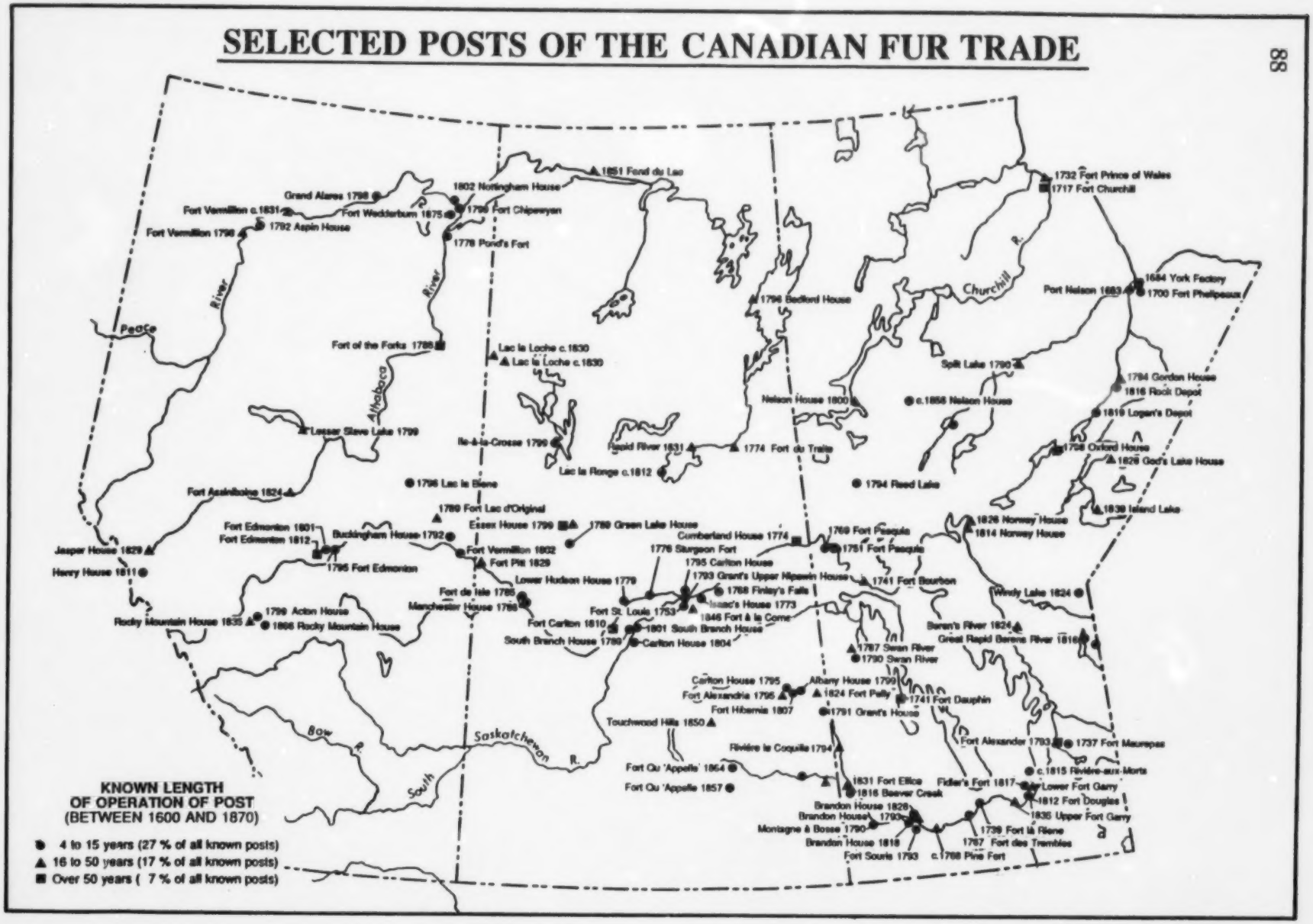
Wright, H.E., 1976: The dynamic nature of Holocene vegetation: a problem in paleoclimatology, biogeography and stratigraphic nomenclature. *Quaternary Research, 6*, 581-596.

Wright, H.E., 1984: Sensitivity and response time of natural systems to climatic change in the late quaternary. *Quaternary Science Review, 3*, 91-131.

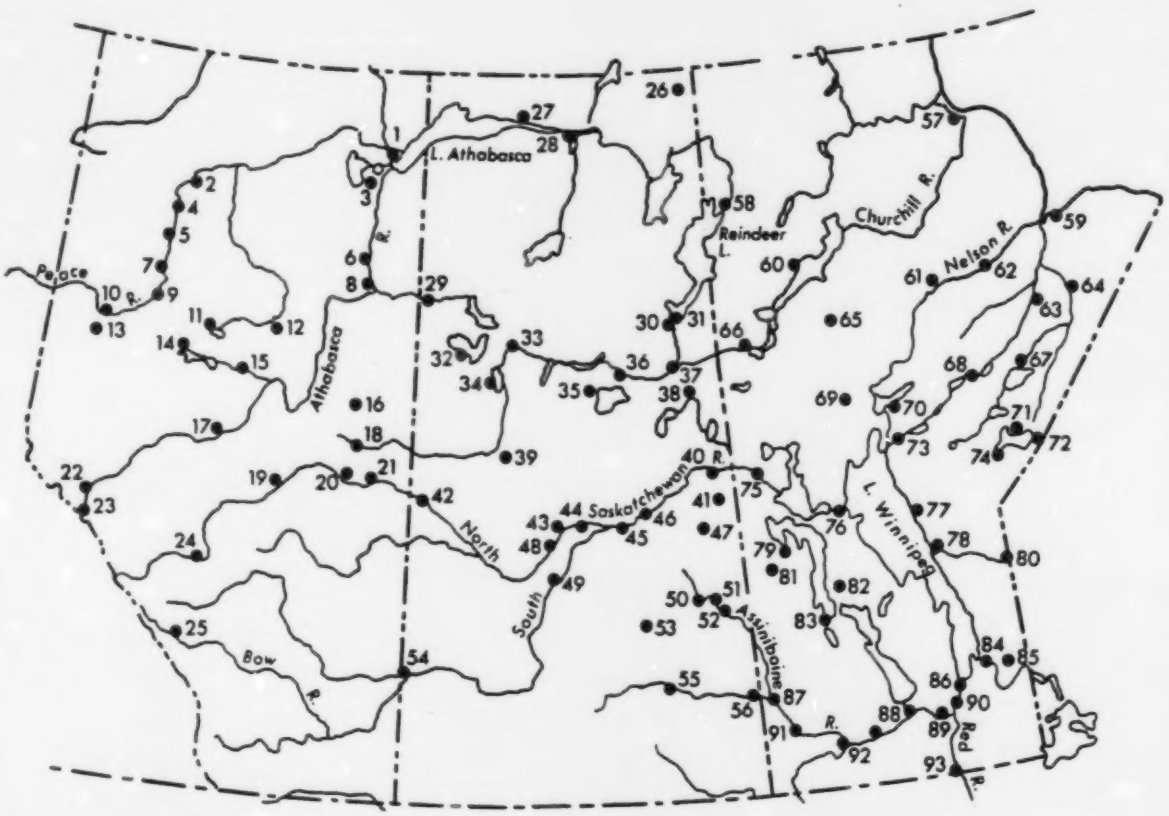
# APPENDIX I

LOCATION INDEX MAP AND NUMERICAL KEY IDENTIFYING TRADING POSTS ACROSS CANADA *(Source: National Atlas of Canada)*

A1.1 POSTS OF THE PRAIRIE FUR TRADE (Dates and Duration)



# SELECTED POSTS OF THE CANADIAN FUR TRADE



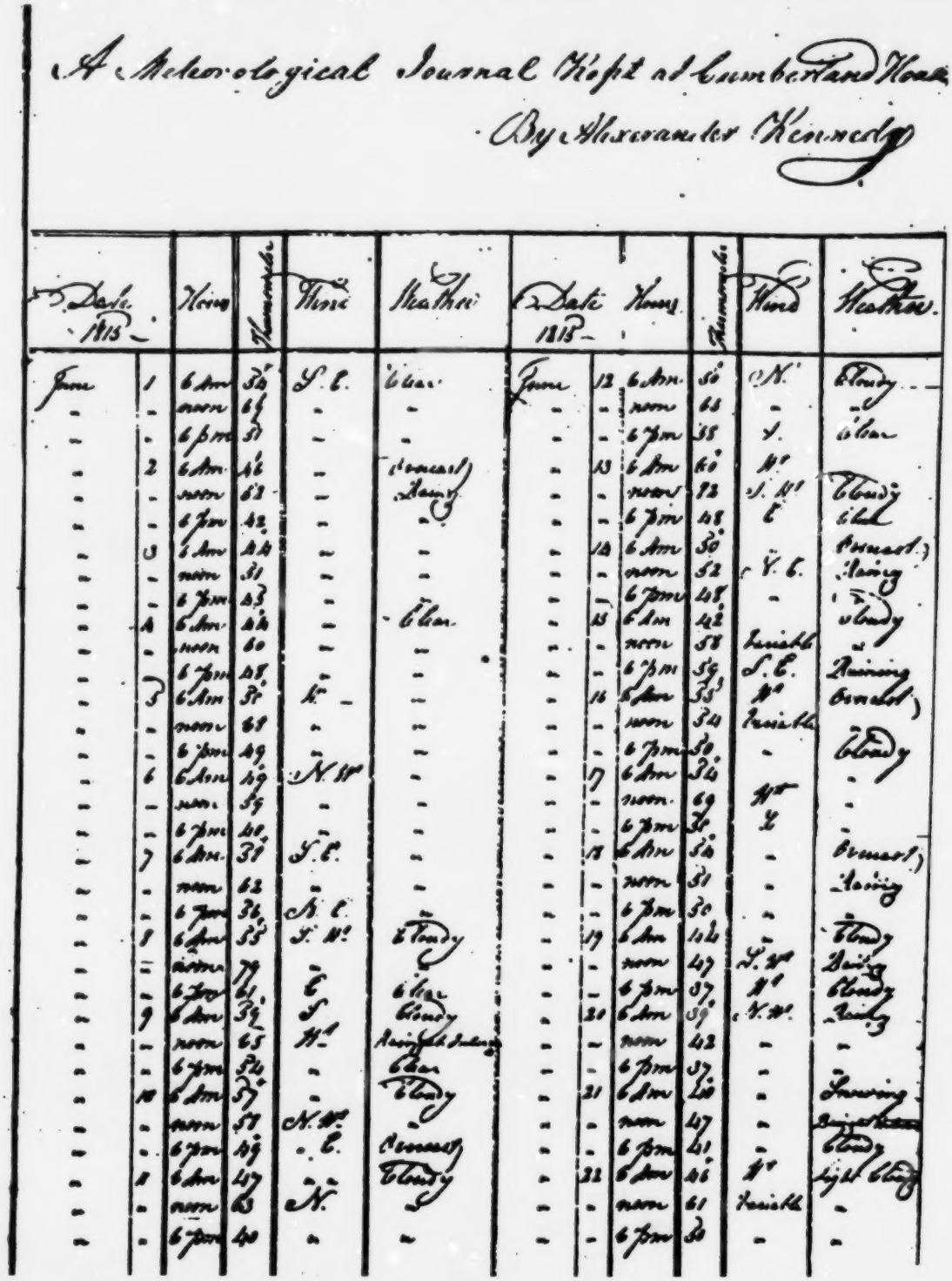

1 - Ft. Chipewyan, NWC-HBC, 1798
2 - Ft. Vermilion, XYC-NWC-HBC, 1800
3 - Pond's Fort, NWC, 1778
4 - Ft. du Tremble - Keg River, NWC-HBC, 1800
5 - Horse Shoe House - Battle River Post, NWC-HBC, 1803
6 - Ft. McMurray - Ft. McKay, HBC, 1874
7 - McLeod's Ft., NWC-HBC, 1791
8 - Ft. of the Forks - Ft. McMurray, NWC-HBC, 1788
9 - Ft. of the Forks - Peace River, NWC-HBC, 1792
10 - Ft. Dunvegan, NWC-HBC, 1805
11 - Whitefish Lake, HBC, 1878
12 - Wabasca - Desmarais, HBC, 1889
13 - Spirit River, HBC, 1888
14 - Lesser Slave Lake, NWC-HBC, 1802
15 - Lesser Slave Lake, NWC, 1799
16 - Lac-la-Biche, NWC-HBC, 1798
17 - Ft. Assiniboine, HBC, 1823
18 - Ft. Lac d'Original - Moose Lake, NWC, 1789
20 - Ft. Augustus - Ft. Edmonton, NWC-HBC, 1795
21 - St. Paul House, HBC, 1866
22 - Buckingham House, HBC, 1792
23 - Jasper House, HBC, 1801
24 - Henry,s House, HBC, 1812
25 - Acton House - Rocky Mountain House, NWC-HBC, 1799
26 - Bow River Ft., NWC, 1802. Sask.
27 - Caribou, HBC, 1930
28 - Fond du Lac, HBC, 1845
29 - Black Lake, HBC, 1959
30 - Portage la Loche, HBC, 1801
31 - Clapham House - Southend, HBC, 1795
32 - Deers River, HBC, 1792
33 - Lac-des-Boeufs - Buffalo Narrows, NWC-HBC, 1790
34 - Pine River - Pasuanak, HBC, 1921
35 - Ile-à-la-Crosse, NWC-HBC, 1776
36 - Lac la Ronge, NWC-HBC, 1778
37 - Rapid River House - Stanley House, Ind-HBC, 1778
38 - Portage du Traite, Ind-NWC-HBC, 1774
39 - Pelican Narrows, NWC-HBC, 1779
40 - Green Lake House, NWC-HBC, 1781
41 - Cumberland House, NWC-HBC, 1774
42 - Pas Mountain House, HBC 1885
43 - Manchester House - Ft. Pitt, HBC, 1786
44 - Hudson's House, HBC, 1778
45 - Prince Albert, HBC, 1868
46 - Ft. St. Louis - Ft. à la Corne, Fr-NWC-HBC, 1753
47 - Ft. Lower Nipawi, Fr, 1748
48 - Egg Lake - Nut Lake, HBC, 1852
49 - Ft. Carlton, HBC, 1795
50 - South Branch House, NWC-HBC, 1788
51 - Ft. Alexandria, NWC-HBC, 1780
52 - Ft. Hibernia - Ft. Pelly, HBC, 1795
53 - Carlton House, HBC, 1796
54 - Touchwood Hills, HBC, 1849
55 - Chesterfield House, XYC-NWC-HBC, 1791
56 - Ft. Qu'Appelle, HBC, 1853
57 - Ft. Esperance, NWC, 1787. Man.
58 - Churchill Factory, HBC, 1717
59 - Lac du Brochet, HBC, 1796
60 - York Factory - Ft. Nelson, Ind-Fr-HBC, 1682
61 - South Indian Lake, HBC-NWC, 1797
62 - Split Lake House, HBC, 1790
63 - Gillam, HBC, 1927
64 - Gordon House - Rock Depot, HBC, 1794
65 - Shamattawa, HBC, 1913
66 - Nelson House, HBC, 1800
67 - Pukatawagan, Ind-NWC-HBC, 1793
68 - God's Lake, HBC, 1825
69 - Oxford House, HBC, 1798
70 - Wabowden, HBC, 1922
71 - Cross Lake, NWC-HBC, 1794
72 - Island Lake, HBC, 1818
73 - Island Lake, NWC, 1803
74 - Jack River House - Norway House, NWC-HBC, 1796
75 - Maria Portage - St. Therese Point, HBC, 1947
76 - Ft. Pasquia - The Pas, Fr-HBC, 1749
77 - Grand Rapids, HBC, 1864
78 - Poplar River, NWC-HBC, 1806
79 - Berens River, HBC, 1814
80 - Shoal River, HBC, 1828
81 - Little Grand Rapids, HBC, 1801
82 - Swan River, NWC-HBC, 1790
83 - Waterhen Lake House, HBC, 1886
84 - Ft. Dauphin, Fr-NWC-HBC, 1741
85 - Ft. Maurepas - Ft. Bas-de-la-Rivière Ft.Alexander - Pine Falls, Fr-NWC-HBC, 1734
86 - Lac-du-Bonnet House - Indian Cap Ft., NWC-HBC, 1804
87 - Rivière aux Morts - Lower Ft. Garry, NWC-HBC, 1803
88 - Ft. Ellice, HBC, 1794
89 - Ft. La Reine - Portage la Prairie, Fr-NWC-HBC, 1738
90 - White Horse Plains House, HBC, 1810
91 - Ft. Gibraltar - Ft. Douglas - Upper Ft. Garry, NWC-HBC, 1807
92 - Ft. Montagne-à-la-Bosse, NWC, 1790
93 - Ft. Souris - Brandon House - Grand Rapids, XYC-NWC-HBC, 1793

# APPENDIX 2

## EXAMPLES OF METEOROLOGICAL JOURNAL AND METEOROLOGICAL ENTRIES IN A NON-METEOROLOGICAL POST JOURNAL

*(Examples of archival meteorological documents)*

A2.1 (HBC ARCHIVES B.49/9/33, WINNIPEG, MANITOBA)



A Meteorological Journal Kept at Cumberland House
By Alexander Kennedy

| Date 1815 | | Hour | Thermr. | Wind | Weather | Date 1815 | | Hour | Thermr. | Wind | Weather |
|---|---|---|---|---|---|---|---|---|---|---|---|
| June | 1 | 6 Am | 50 | S.E. | Clear | June | 12 | 6 Am | 50 | N. | Cloudy |
| - | - | noon | 64 | - | - | - | - | noon | 68 | - | - |
| - | - | 6 Pm | 51 | - | - | - | - | 6 Pm | 58 | N. | Clear |
| - | 2 | 6 Am | 46 | - | Snow and Hail | - | 13 | 6 Am | 60 | N. | |
| - | - | noon | 63 | - | Hail | - | - | noon | 72 | N. N.E. | Cloudy |
| - | - | 6 Pm | 42 | - | - | - | - | 6 Pm | 68 | E. | Clear |
| - | 3 | 6 Am | 44 | - | - | - | 14 | 6 Am | 50 | | Snow and |
| - | - | noon | 51 | - | - | - | - | noon | 52 | E. E. | Raining |
| - | - | 6 Pm | 43 | - | - | - | - | 6 Pm | 48 | - | - |
| - | 4 | 6 Am | 44 | - | Clear | - | 15 | 6 Am | 42 | | Cloudy |
| - | - | noon | 60 | - | - | - | - | noon | 58 | Variable | - |
| - | - | 6 Pm | 48 | - | - | - | - | 6 Pm | 56 | S.E. | Raining |
| - | 5 | 6 Am | 51 | E. | - | - | 16 | 6 Am | 55 | N. | Snow and |
| - | - | noon | 69 | - | - | - | - | noon | 54 | Variable | - |
| - | - | 6 Pm | 49 | - | - | - | - | 6 Pm | 50 | - | Cloudy |
| - | 6 | 6 Am | 49 | N. N.E. | - | - | 17 | 6 Am | 54 | - | - |
| - | - | noon | 54 | - | - | - | - | noon | 69 | N.E. | - |
| - | - | 6 Pm | 40 | - | - | - | - | 6 Pm | 56 | E. | - |
| - | 7 | 6 Am | 39 | S.E. | - | - | 18 | 6 Am | 54 | - | Snow and |
| - | - | noon | 62 | - | - | - | - | noon | 51 | - | Raining |
| - | - | 6 Pm | 36 | S.E. | - | - | - | 6 Pm | 50 | - | - |
| - | 8 | 6 Am | 35 | S. N.E. | Cloudy | - | 19 | 6 Am | 52 | - | Cloudy |
| - | - | noon | 71 | E. | Clear | - | - | noon | 47 | S.W. | Rain |
| - | - | 6 Pm | 61 | S. | Cloudy | - | - | 6 Pm | 37 | N.E. | Cloudy |
| - | 9 | 6 Am | 34 | N.E. | Raining Snow | - | 20 | 6 Am | 39 | N. N.E. | Raining |
| - | - | noon | 65 | - | Clear | - | - | noon | 42 | - | - |
| - | - | 6 Pm | 54 | - | Cloudy | - | - | 6 Pm | 37 | - | - |
| - | 10 | 6 Am | 57 | - | - | - | 21 | 6 Am | 40 | - | Snowing |
| - | - | noon | 58 | N.N.E. | - | - | - | noon | 47 | - | Snow and Rain |
| - | - | 6 Pm | 49 | E. | Cloudy | - | - | 6 Pm | 41 | - | Cloudy |
| - | 11 | 6 Am | 47 | - | - | - | 22 | 6 Am | 46 | N.E. | Light Clouds |
| - | - | noon | 63 | N. | - | - | - | noon | 61 | Variable | - |
| - | - | 6 Pm | 40 | - | - | - | - | 6 Pm | 50 | - | - |

(Hudson Bay Company Archives (microfilm copy). Courtesy Provincial Archives of Manitoba)

A2.2 ENTRIES IN A POST JOURNAL - NON-METEOROLOGICAL (HBC ARCHIVES B.239/A/136, WINNIPEG, MANITOBA)

December 1824

Sunday 26th Ther 15 below Zero W. Prayers read.

Monday 27th Ther 8 above Zero to Several of the Men employed themselves

Tuesday 28th Ther 15 above Zero to the Indians arrived from their hunting ground

Wednesday 29th ~~Ther from 24 to 8 above Cloudy~~ to the Brim that ordered before Christmas returned to Pennaltaus to resume their Work Sent three Crains to Sans Soucis for Partridges the Men at the fort resumed their work few Men arrived from Pennaltaus

Thursday 30th Ther 28 above Cloudy W. with Snow prepared the fort Variously employed

Friday 31st Ther 8 above Cloudy Weather Snowing great part of the day the Crains returned from Sans Soucis Sent 150 Partridges

January 1825

Saturday 1st Ther at Zero Snowing Last of the day at the usual custom the new year was ushered in by a salute from the Men Which Consists in an Orderly discharge of their Arms in the evening Gave a dram to all hands

(Hudson Bay Company Archives (microfilm copy). Courtesy Provincial Archives of Manitoba)

## A2.3 EXAMPLES OF MONTHLY OF WEATHER REPORTED IN THE *NORTHWESTER*, RED RIVER SETTLEMENT, 1861

### JANUARY.

| | |
|---|---|
| Maximum of the month, 13th, | 36 |
| Minimum " " 10th, | -37 |
| Highest daily mean, 13th, | 19 |
| Lowest " " 9th and 10th, | -17 |
| Mean of the first week, | -8 |
| " " second week, | -5 |
| " " third week, | 6 |
| " " fourth week, | 3 |
| Mean of the month, | -1 |
| Range of the month, | 53 |

### FEBRUARY.

| | |
|---|---|
| Maximum of the month, 28th, | 41 |
| Minimum " " 7th, | -40 |
| Highest daily mean, 28th, | 33 |
| Lowest " " 7th, | -29 |
| Mean of first week, | -7 |
| " second week, | 9½ |
| " third week, | 11 |
| " fourth week, | 10 |
| Mean of the month, | 11 |
| Range of the month, | 81 |

### MARCH.

| | |
|---|---|
| Maximum of the month, 31st, | 44 |
| Minimum, " " 4th, 6th, and 25th, | -16 |
| Highest daily mean, 31st, | 33 |
| Lowest " " 4th and 16th, | -7 |
| Mean of first week, | 12 |
| " second week, | 9½ |
| " third week, | 9½ |
| " fourth week, | 12½ |
| Mean of the month, | 11 |
| Range of the month, | 60 |

It will be seen from the above tables that the 7th of February was the coldest day, being 40 degrees below zero, and that the 13th December, which was 30 degrees below, was the next coldest day of the winter now passing away; also, that January was on the whole, the coldest month, the average being almost 1 degree below zero. The average of all the other months was above zero, as follows:—October, 45½; November, 4; December, 2½; February and March, the same—11 degrees. The first week of January was the coldest, and next to it stands the first week of February—the former being on the whole 8 and the latter 7 degrees below zero. Of the three months, December, January, and February (which constitute our winter proper), the thermometer stood highest in the last-mentioned: on the 28th, it was 41 above zero at noon, and the day averaged 33. The next highest was in December: on the 18th, at noon, it indicated 30, and the day averaged 27.

The foregoing will give a good idea of a Red River winter. We only add that this last winter has been more than average in length and in quantity of snow, but not in severity.

## METEOROLOGICAL.

The following table of observations, compiled from the Meteorological Register kept at Fort Garry by Lance-Sergeant Bedson, will give the most reliable idea of the weather here during the last month. It is scarcely necessary to observe that the figures given are all plus—above zero:—

| | 7 A.M. | NOON. | 7 P.M. |
|---|---|---|---|
| October 1, | 47 | 51 | 49 |
| " 2, | 45 | 58 | 49 |
| " 3, | 46 | 60 | 58 |
| " 4, | 47 | 66 | 60 |
| " 5, | 56 | 65 | 51 |
| " 6, | 53 | 61 | 53 |
| " 7, | 43 | 49 | 43 |
| " 8, | 33 | 62 | 43 |
| " 9, | 35 | 61 | 45 |
| " 10, | 33 | 39 | 33 |
| " 11, | 31 | 37 | 29 |
| " 12, | 24 | 41 | 37 |
| " 13, | 27 | 47 | 44 |
| " 14, | 33 | 51 | 54 |
| " 15, | 44 | 65 | 51 |
| " 16, | 33 | 64 | 52 |
| " 17, | 33 | 55 | 50 |
| " 18, | 40 | 57 | 54 |
| " 19, | 48 | 70 | 56 |
| " 20, | 45 | 72 | 60 |
| " 21, | 37 | 53 | 45 |
| " 22, | 37 | 60 | 51 |
| " 23, | 36 | 56 | 46 |
| " 24, | 33 | 42 | 39 |
| " 25, | 31 | 39 | 32 |
| " 26, | 31 | 44 | 39 |
| " 27, | 28 | 47 | 45 |
| " 28, | 35 | 44 | 39 |
| " 29, | 39 | 47 | 44 |
| " 30, | 40 | 45 | 40 |
| " 31, | 40 | 44 | 37 |

(Courtesy Winnipeg Centennial Library Archives)

# APPENDIX 3

## SOURCES OF PROXY METEOROLOGICAL DATA FOR THE PRAIRIES

### A.3.1 HISTORICAL DOCUMENTS

**Ottawa**

1. National Archives of Canada, 395, Wellington Street, Ottawa, Ontario K1A 0N3
2. National Museums of Canada, Ottawa, K1A 0M8

**Manitoba**

2. Hudson's Bay Company Archives, 200 Vaughan Street, Winnipeg, Manitoba R3C 1T5
3. Provincial Archives of Manitoba, 200 Vaughan Street, Winnipeg, Manitoba R3C 1T5
4. John E. Robbin's Library, Brandon University, Brandon Manitoba R7A 6A9
5. Winnipeg, Public Library, Graham Avenue, Winnipeg, Manitoba
6. Manitoba Museum of Man and Nature, 190 Rupert Avenue, Winnipeg, Manitoba R3B ON2
7. Manitoba Department of Cultural Affairs and Historical Resources, 177 Lombard Avenue, Winnipeg, Manitoba

**Saskatchewan**

8. Saskatchewan Archives Board, University of Regina, Regina, Saskatchewan S7N 0A2
9. Saskatchewan Archives Board, University of Saskatchewan, Saskatoon, Saskatchewan S7N 0W0
10. Gabriel Dumont Institute of Native Studies and Applied Research, 121 Broadway Avenue East, Regina, Saskatchewan S4N 0Z6

**Alberta**

11. Provincial Archives of Alberta, 12845-102 Avenue, Edmonton, Alberta T5N 0M6
12. Alberta Culture, Historic Resources, Historic Site Service, Old St. Stephen's College, 8520-112 Street, Edmonton, Alberta T6G 2P8
13. Glenbow Museum, 130-9 Avenue S.E., Calgary, Alberta T2G 0P3
14. Calgary Public Library, 616 Macleod Trail S.E., Calgary, Alberta T2G 2M2

**Ontario**

15. Champlain Society, Toronto, Ontario
16. Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario M5S 2C6

## A.3.2. PREHISTORIC PROXY DATA

The following institutions include laboratories and research personnel active in one or more aspects of paleoclimatological research relevant to the Canadian Prairies.

**Manitoba**

1. The University of Manitoba, Winnipeg, Manitoba R3T 2N2
   (a) Department of Biology (G.T. Shay)
   (b) Department of Earth Sciences (W.M. Last and J.T. Teller
   (c) Department of Geography (A.J.W. Catchpole and D.W. Moodie)
2. The University of Winnipeg, Winnipeg, Manitoba, Department of Geography (T. Ball and W.F. Rannie)
3. Manitoba Department of Energy and Mines, 535-330 Graham Avenue, Winnipeg, Manitoba R3C 4E3 (E. Nielsen)
4. Manitoba Museum of Man and Nature, 190 Rupert Avenue, Winnipeg, Manitoba R3B 0N2 (W.B. McKillop)
5. Manitoba Department of Cultural Affairs and Historical Resources, 177 Lombard Avenue, Winnipeg, Manitoba (L. Pettipas)

**Saskatchewan**

6. National Hydrology Research Institute, Saskatoon, Saskatchewan S7N 3H5 (G. Holdsworth)
7. The University of Saskatchewan, Saskatoon, Saskatchewan S7N 0W0 (E. Walker, Department of Anthropology)
8. Saskatchewan Research Council,

**Alberta**

9. The University of Calgary, Calgary, Alberta T2N 1N4
   (a) Department of Archeology (B.O.K. Reeves)
   (b) Department of Geography (S. Harris, D. Smith)
   (c) Department of Geology (L.V. Hills)
10. University of Alberta, Edmonton, Alberta T6G 2H4
    (a) Department of Anthropology (C.E. Schweger)
    (b) Department of Botany (M. Hickman)
    (c) Department of Geology (N.W. Rutter)
11. Northern Forestry Centre, Canadian Forestry Service, Agriculture Canada, 5320-122 Street, Edmonton, Alberta T6H 3S5

Miscellaneous

12. The University of Toronto, Toronto, Ontario, Scarborough College, Ontario M1C 1A4 (J.C. Ritchie)
13. Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8 (R.J. Mott, M. Luckman)
14. The University of Western Ontario, London, Ontario, Department of Geography (G.M. McDonald)
15. Simon Fraser University, Burnaby, British Columbia, Department of Biology (R.E. Vance, R.W. Mathewes)

A.3.2.1 KEY JOURNALS

- *Canadian Journal of Earth Sciences*
- *Quaternary Research*
- *Arctic and Alpine Research*
- *Journal of Applied Meteorology*
- *Journal of Paleontology*
- *Canadian Journal of Botany*
- *Canadian Journal of Forestry Science*
- *Quaternary Science Review*
- *Canadian Journal of Archeology*
- *Canadian Journal of Anthropology*
- *Manitoba Archaeological Quarterly*
- *Saskatchewan Archeology*
- *Alberta Archaeological Review*
- *Plains Anthropology*
- *Journal of Ecology*